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PREPARED BY

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(9) FINAL REPORT. Jun 79 - Jun 81

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Two experiments were performed with experienced sonar technician listeners in an effort to identify perceptual dimensions underlying the classification of aurally presented sonar signals. The first experiment which was essentially a replication of work by earlier investigators, had the objective of identifying possible differences in the perceptual space of naive and experienced listeners. The second experiment was an extension of the first using a larger, more representative signal set. In addition,

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the perceptual dimensions that emerged were related to judgments of target classification.

It was found that: 1) where common sets of sonar signals are used as stimuli, the group perceptual space of naive and experienced sonar listeners is highly similar; 2) experienced sonar listeners attach different salience or importance to particular dimensions than do naive listeners; 3) the number of dimensions in the group perceptual space is a function of the representativeness of the signal set; 4) most sonar signals are quite complex perceptually, and project on several dimensions; 5) very strong projections on some of the experimentally identified dimensions are associated with a high degree of classification success, but signals that lack strong projections on any dimension are often erroneously classified; 6) experienced sonar listeners classify signals in accord with how strongly the signals resemble certain target class stereotypes; this may or may not result in successful classification of particular examples.

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INTRODUCTION

One of the most complex and operationally important skills of Navy Sonar Technicians is their ability to classify a variety of aurally presented broadband sonar signals into a limited set of tactically significant target classes. Sonar Technicians perform this task with various levels of success (Mackie, Parker, and Dods, 1968; Dick, Mecherikoff, and Mackie, 1970; Mecherikoff, 1974), but the highly skilled ones have yet to be out-performed by oft-proposed automatic methods. The signals are highly complex and noisy. The clues to correct classification are often subtle and difficult to detect, the logical relationships between clues and target classes are quite complex, targets of different classes may sometimes sound very much alike, targets of the same class may sound very different, and a particular target may resemble a typical member of another class more than a typical member of its own class (Mecherikoff, 1974).

The process by which Sonar Technicians perform auditory target classifications is poorly understood. Undoubtedly both feature extraction and decision processes are involved and some attempts have been made to systematize these processes through the use of explicit classification logic (decision trees). Training in passive sonar auditory target classification reflects both of these processes. That is, students are taught to recognize particular clues that are associated with specific types of sound sources and, since these clues are rarely the exclusive property of a particular target class, to engage, albeit quite informally, in an inferential decision process reflecting the relative likelihood that the signal source belongs to one or another target class.

Clue recognition training is accomplished by associating common labels such as "hissing," "roaring," or "humming" to recorded examples of target signals judged to exhibit these subjective characteristics, and classification decisions are arrived at using a more or less explicit logic describing the likelihood that various combinations of these clues will be displayed by targets of different classes. In practice, the extent to which the feature extraction and decision making processes actually follow the training doctrine, or whether that doctrine is in fact optimal, is not clear.

The output of the auditory classification process is usually a categorical statement of probable membership in one of four basic target classes: (1) submarine; (2) surface warship; (3) cargo ship; and (4) lightcraft. Various degrees of refinement are sometimes possible within these classes, and certain aspects of the target's behavior can also sometimes be discerned (for example, its operating RPM). In addition, it is necessary that target-like sounds associated with certain natural phenomena, i.e. sea life, rain squalls, etc., be classified as such. Occasionally, these and other sources produce signal patterns that closely resemble members of one or more of the ship classes.

Whatever the nature of the feature extraction and decision making processes, there is evidence that they take place rapidly. Initial impressions of the probable target type often are formed in less than 30 seconds although a thorough logical analysis of the target's characteristics based on a consideration of the presence or absence of a multiplicity of clues may take longer (Mecherikoff, 1974). In fact, the operational significance of auditory target classification stems in part from the rapidity with which the classification can be made. Sophisticated acoustic analysis equipment which can provide considerably more detail about specific characteristics of the sound source requires a considerably longer signal history for the performance of its functions, although it does provide a more refined classification output than auditory methods. Auditory methods remain operationally significant because of the short analysis time required and their ability to process signals that may have quite short durations. The weakness of auditory classification lies in the requirement for substantial training in "tuning" the feature extraction process,[1] in the difficulty of learning how to apply a systematic classification logic, and in the fundamental overlap of feature space among the several target classes of interest. Both the perceptual and decision making processes are highly complex and research has shown that Sonar Technicians not only vary widely in their ability to perform the task but that periodic refresher training is absolutely essential (Mackie et al., 1968; Mecherikoff, 1974).

In recent years, important advances have been made in understanding the perceptual processes involved in the detection and discrimination of simple acoustic stimuli, but relatively little is

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[1]In the words of Howard, Ballas, and Burgey (1978), the feature extraction process is "tuned" to select perceptually important information from the output of a preliminary analysis stage.

known about the psychological processes that underlie the classification and recognition of complex acoustic signals (Howard, et al, 1978). The problem of how to identify the perceptual dimensions that underlie sonar signal recognition has to a large extent been a methodological one. For example, Mecherikoff (1974) attempted to use triadic comparisons of sonar signal recordings to identify the dimensions involved in discriminating among signals from a variety of target classes. In this method the subject judges which of three sequentially presented auditory stimuli is most different from the other two. In addition to the fact that this approach involves an enormous number of triads with even a modest number of stimuli, Mecherikoff found that experienced listeners were inconsistent in their judgments, a problem that he attributed in part to the heterogeneity and complexity of the recorded signals. He concluded that a fundamental problem in the use of the triadic method with very complex stimuli is that the listener may attend to different features of the same stimulus at different times, and of course, under these circumstances, the reliability of the judgments of similarity and difference may be seriously affected. In fact, Mecherikoff's listeners sometimes reported such an attention shift even during their evaluation of a single triad.

It is also evident that the stimulus characteristic attended to depends on the particular triad; for example, "hiss" might be an outstanding characteristic of one sound in a particular triad, but "hiss" might be completely ignored in another triad if all of the sounds happen to have "hiss." If there are many characteristics in each sound to which the subject may attend, it will require a very large number of stimuli and many replications of the triad to identify all of the dimensions, particularly if the dimensions of practical importance are not the most obvious ones.

Mecherikoff also found that the two or three clusters which emerged from the triadic comparisons made by personnel naive with respect to sonar classification bore only tenuous relationships to established sonar classification clues and target classes. The problem in his view was that the clusters, factors, or dimensions which may be most readily identified through this type of analysis may not relate to the categories of practical interest (in this case, target classes); rather, they may be factors which are recognized as irrelevant by experienced Sonar Technicians.

> Some of the most outstanding distinctions between passive sonar sounds as heard by naive listeners are based on pre-potent characteristics which happen to be largely unrelated to target class, such as signal-to-noise ratio, overall loudness of the recording, and background noise characteristics. (Mecherikoff, p. 7)

However, Mecherikoff also noted that using experienced sonarmen as experimental participants introduces the genuine danger that similarity judgments may be made on the basis of inferred target class, rather than on perceptual characteristics of the signal.

Recent work by Howard (1976) appears to have largely solved some of these methodological problems. New multidimensional scaling techniques have been developed which are designed to decompose a set of subjective proximity data into a space spanned by n-orthogonal dimensions. These dimensions may be interpreted as reflecting the psychological features underlying the perceptual structure of the stimulus set. Howard used the INDSCAL model (Carroll and Chang, 1970), which operates on individual observer's judgments of similarity between all possible pairs in a signal set to extract the dimensions on which the stimuli differed. This model assumes that each individual observer's judgment of the similarity between pairs of signals is a decreasing linear function of the interstimulus distance in an underlying perceptual space. An advantage of the method is that information about individual differences in similarity judgments are preserved. It produces both an overall group perceptual space, and a vector of saliency weights for each observer reflecting the relative importance or saliency of each dimension (Howard, 1976).

Howard used this method to explore the group perceptual space and individual saliency weights underlying the judgments of similarity of 8 target signals recorded during actual sonar operations. In an attempt to relate the perceptual dimensions to the physical characteristics of the signals, Howard also analyzed the frequency spectrum of the signals in 1/3 octave bands, thus approximating the response bandwidth of the human ear. The INDSCAL analysis produced a 3-dimensional solution that Howard felt was adequate to describe the perceptual space of the 8 underwater sounds. The solution accounted for an estimated 63 percent of the variance in the observers' similarity ratings. When the results of this analysis were compared with the physical analysis, each of the three perceptual dimensions was found to correlate reliably with an interpretable acoustic parameter of the stimuli. The perceptual dimensions, ψ_1 (homogeneity versus heterogeneity of sound) and ψ_3 (degree of "tinniness") were found to match two steady state parameters ϕ_1 and ϕ_2, where ϕ_1 reflected the modality (unimodal versus bimodal) of the physical spectrum and ϕ_2 represented a skewness factor. Signals having high ϕ_2 values had relatively more high frequency information than low frequency information. Whereas ϕ_1 and ϕ_2 reflected steady state components of the signals, Howard noted that some signals displayed a perceptible low frequency periodicity (dimension ψ_2) which would not be evident in the 1/3 octave spectra. Therefore, a spectrographic analysis was performed on 2.5 second samples of each stimulus and a third physical parameter, ϕ_3, representing low-frequency periodicity was identified.

While Howard found that all of his observers used all three perceptual dimensions to a greater or lesser degree in making their similarity judgments, he also found that the saliency of each dimension for different individuals depended upon the listener's musical background. A group of musically sophisticated listeners tended to weight the periodic parameter ψ_2 more heavily than the steady-state parameter ψ_1, while the opposite was observed for musically naive participants. He speculated that musically experienced observers had learned, through their musical training, to emphasize the periodicity of complex sounds. In other words, feature salience may depend to a large extent on subjective factors that are influenced by prior experience and training.

Howard's early work did not focus on feature extraction and the classification process. Indeed, the listeners were naive with respect to the source of the signals, and their attention was not focused on any particular attribute. The criteria for their similarity ratings was totally unspecified, and no classification response was required. In a subsequent study, however, Howard, Ballas and Burgey (1978) extended the work to feature extraction and decision processes in classification. In this study, the relationship between the perceptual features identified in a multi-dimensional scaling analysis and the decision stage of the auditory classification process was investigated. Howard, et al., were able to show that the perceptual dimensions associated with 16 amplitude modulated noise signals were used differentially by two groups of listeners who learned (through feedback) to selectively focus their attention on the (arbitrarily) more important of two dimensions. A selective tuning process was postulated which, with experience, accompanies the learning process in such a way that the listener reduces the overall uncertainty about the two signal parameters. That is, as learning progresses, the listener observes that the two features are not equally important in discriminating among the various target classes. At this point selective tuning occurs to reduce the variability of the more important feature relative to the less important one. Howard, et al., concluded that

> ...listeners have considerable flexibility in their feature extraction processes. A flexible feature extraction process of this sort can readily adapt to changing task demands. In the present study... a clear difference in relative feature importance or salience was observed in the similarity judgment and classification tasks. In Experiment 1, where the data were observed in a pair-wise comparison procedure,

> listeners tended to emphasize signal quality (relative to tempo, 46 and 23 percent of the variance, respectively). Quite a different picture emerged in Experiment 2, where the listeners were trained to classify the sounds into eight categories. In this case, the relative subjective importance of the two features reflected the criteria used by the experimenter to determine the eight categories. ...These findings clearly stress the role of task factors in determining feature saliency. (pp. 54-55)

These two studies raised important questions about the perceptual dimensions and saliencies associated with the classification of sonar signals by experienced Sonar Technicians. It was of interest to determine:

1. How many underlying perceptual dimensions account for the variance in signal similarity judgments of experienced Sonar Technicians as opposed to sonar naive listeners.

2. Whether these perceptual dimensions are the same or different from those identified using naive personnel as listeners.

3. Whether experienced Sonar Technicians use different saliencies than naive personnel in judging the differences among sonar signals.

4. Whether the perceptual dimensionality of the discrimination space differs, if a broader sample of sonar signals is used as the stimulus pool.

5. How target classification judgments relate to the perceptual and physical dimensions underlying the similarity judgments of experienced Sonar Technicians.

6. How perceptual/conceptual stereotypes of various target classes, held by experienced Sonar Technicians, relate to underlying perceptual or physical space.

7. How well a 1/3 octave analysis identifies the physical dimensions related to the perceptual dimensions employed by experienced Sonar Technicians and whether a higher resolution physical analysis produces a stronger correspondence between physical and perceptual dimensions.

The present study was designed to answer these and related questions. To answer Questions 1, 2, and 3, essentially a replication of Howard's initial experiment was performed, using experienced Sonar Technicians instead of sonar-naive personnel as the experimental listeners. To answer Question 4, a second experiment was performed, again using experienced Sonar Technicians as participants, but employing a larger sample of operationally relevant sonar target signals as stimuli. Question 5, which had not been addressed in Howard's earlier work, was investigated by eliciting the classification judgments of experienced Sonar Technicians to the same stimuli that were used to elicit similarity judgments. Since it could not be determined a priori how the sample of experimental stimuli related to the classification stereotypes of experienced sonar personnel, Question 6 was addressed by determining the judged similarity of each experimental stimulus to each of several conceptual stereotypes of the target classes employed operationally during sonar system operation. Finally, Question 7 was explored by performing a detailed physical analysis of each sonar signal comprising the larger stimulus set.

EXPERIMENT 1: REPLICATION OF HOWARD'S STUDY USING EXPERIENCED SONAR TECHNICIANS AS LISTENERS

Hypotheses

The first experiment was designed to test the following hypotheses:

1. When experienced Sonar Technicians judge the similarity of sequentially presented pairs of sonar signals, the discriminal processes reflect a larger number of underlying perceptual dimensions than when naive observers judge the same stimuli.

2. Some of the perceptual dimensions employed by sonar personnel will be the same as those employed by sonar-naive listeners and others will be different.

3. Some of the saliencies in judging the similarities and differences among sonar signals will be different for sophisticated as opposed to naive observers of sonar signals.

Procedure

Experimental Stimuli

The experimental stimuli were constructed from tape-recorded copies of the 8 recorded sonar signals employed by Howard (1976). (The authors are indebted to Howard for making these materials available.) The first step in their development was to record a 7-second sample of each signal onto an endless tape loop which could be played back on a MacKenzie 20-channel audio storage unit (APR-20). During this process, a specially built amplifier-compressor was used to eliminate any large amplitude variations among the various target recordings.

All possible pairs of the 8 signals were then re-recorded into the basic presentation format which was as follows: 3 seconds of stimulus A, followed by 1 second of silence, followed by 3 seconds of stimulus B. This procedure was followed until all possible pairs of the 8 stimuli had been composed. A computer-based random number generator then dictated the order in which the pairs of stimuli were assembled into the test. All possible stimulus pairs were generated twice. Thus, Test 1 was comprised of 56 paired stimuli, in random order, with each stimulus pair being presented twice.

The test stimuli represented audio signals from surface ships, submarines, and natural phenomena:

1 Flutter (FL); (associated with propellers)
2. Sheet cavitation (SC); (associated with propellers)
3. Biologics (BI); (sounds associated with sea life that could be confused with ship sounds)
4. Compressed cavitation (CC); (sounds associated with propellers)
5. Torpedo (TO)
6. Diesel engine (DE)
7. Rain squall (RS)
8. Steam noise (SN)

The sounds in this stimulus set are quite diverse, although it would be difficult to defend it as representing the full spectrum of sounds that sonar personnel are expected to identify. The importance of this point is discussed later in conjunction with Experiment 2.

Participants

Twenty-six experienced Sonar Technicians served as listeners. All were volunteers. Each signed a voluntary consent form and was informed of his rights of privacy prior to participating in the experiment. Eleven participants were recruited from the Fleet Submarine Training Detachment, Sa· Diego and 15 from the Fleet Anti-Submarine Warfare

Training Center, San Diego. They ranged in rate from third-class to chief petty officer; all had at least one tour of duty involving passive sonar listening responsibilities aboard U.S. submarines.

Apparatus and Test Environment

The 56 items comprising Test 1 were played to small groups of participants ranging in number from 6 to 12 on a Sony TC-252 reel-to-reel tape deck. The signals were passed through the amplifier-compressor and presented via Pioneer SE-205 headphones. Ten randomly selected stimulus pairs were presented initially to acquaint the participants with the comparison task. These initial responses were not scored. Later, responses to these stimulus pairs were scored when they reappeared in the body of the test. After assurance that the requirements of the experimental task were fully understood, the tape recorder was turned on and the 56 test items presented.

Howard (1976) had employed a somewhat different method of stimulus presentation wherein each of two tape recorders served as a continuous stimulus source throughout the experiment. The stimuli were delivered to the listener's headphones by means of computer-controlled relays. Howard also employed a 3-second presentation of each member of a stimulus pair with a 1-second interstimulus interval. After an opportunity to make an initial similarity judgment, the participants were allowed to listen again to a particular pair of stimuli as many times as they wished. The number of voluntary "second listens" was thus uncontrolled, and it is clear that not all participants listened twice to each pair.[2] In the present study, the number of "second-listens" was controlled by immediately re-presenting each stimulus pair a second time, following its initial presentation. Thus, the full sequence for each item was "Item number __"; Stimulus A (3 seconds)--pause (1 second)--Stimulus B (3 seconds); "Item number __" --Stimulus A (3 seconds)--pause (1 second)--Stimulus B (3 seconds). This procedure was adopted to insure that the listener had an opportunity to judge the similarity of each pair of stimuli a second time if is was needed. We felt this would be an effective technique for coping with momentary lapses of attention that might otherwise introduce error variance in the judgment process, particularly in the second experiment where the number of stimulus pairs was quite large. Howard's procedure very likely accomplished the same result but required computer control of the stimulus presentation.

Response Requirements

The participants responded to each stimulus pair in terms of "how similar they sound to you" by placing a checkmark at any point along a 7-point response scale (Figure 1). Howard had employed a five-point scale with the instruction that a rating of "1" should be assigned to very dissimilar stimuli and a rating of "5" should be assigned to very similar sounding stimuli. We employed a somewhat expanded scale with additional verbal modifiers because of our concern that sophisticated judges might wish to discriminate more finely than naive ones and that a 5-point response scale might not be sufficient for the

---

[2] Howard reported that on the average, the number of times each stimulus pair was listened to was 1.71 for musically experienced observers and 1.33 for musically inexperienced observers.

TEST A

Please judge each pair of sounds according to how similar they sound to you. Check (✓) anywhere from 1 to 7, depending only on how the sounds compare. Disregard what you think may be their source.

Signal							
1.	1	2	3	4	5	6	7
	Extremely Different	Very Different	Intermediate			Very Similar	Nearly Identical
2.	1	2	3	4	5	6	7
3.	1	2	3	4	5	6	7
4.	1	2	3	4	5	6	7
5.	1	2	3	4	5	6	7
6.	1	2	3	4	5	6	7
7.	1	2	3	4	5	6	7
8.	1	2	3	4	5	6	7
9.	1	2	3	4	5	6	7
10.	1	2	3	4	5	6	7

Figure 1. Example of response scale used for judgments of stimulus pair similarity.

purpose. In particular, we were concerned that the ratings of these rather diverse stimuli, in terms of the underwater sound phenomena they represented, might be bunched towards the "dissimilar" end of the scale and some of the discrimination between certain pairs might therefore be reduced or lost.

The listeners performed their comparison task in a standard classroom environment at the two training facilities. The environment was quiet, though not sound-attenuated. Since the stimuli were presented over individual headphones and were clearly supra-thereshold, it seems doubtful that background noise interfered with the judgmental task. Howard's listeners, however, had been tested in sound-attenauted booths.

Results -- Experiment 1

Reliability of Judgment

Since the Sonar Technicians were required to perform a task that, in their view, probably bore an uncertain relationship to their regular operational task, it was necessary to determine whether their judgments of similarity were reliable. In particular, it was of interest to determine the extent to which the two independent groups of sonar personnel agreed with one another.

The raw data were the scale values assigned to each item (stimulus pair) which ranged from 1 to 7 (no attempt was made to score the responses to a finer level than the nearest whole unit.) Average score values were computed for the first and last 14 items for each of two participant groups: (1) the 11 participants from the Submarine Training Detachment and (2) the first 11 participants from the Fleet ASW Training Center. The mean scale value was computed for each of these 28 items and rank-ordered for each group of participants. Rank-order correlations were then computed which reflected the level of agreement between groups of their judgment of similarity. The rank-ordered correlations were .90 for the first 14 items and .89 for the last 14 items. Thus, the two groups strongly agreed on the extent of similarity among these selected test items. Further, there was no evidence that the judgments were any more or less reliable during the first quarter of the test than during the last quarter. These results are quite comparable to those of Howard who reported a correlation of .87 between the mean ratings assigned by his observers on the first and second presentations of the 28 stimulus pairs.

Though these results can be considered supportive of high group reliability in judging the similarities and differences of the stimulus pairs, the question of observer reliability is also pertinent because the method of multidimensional scaling to be employed in the main data analysis (SINDSCAL) retains individual differences in the saliencies of each dimension in accounting for the total variance in the judgments. Since each stimulus pair was presented twice, the reliability of individual judgments was estimated by computing the correlation between the scale values assigned to each stimulus pair on the first and second presentations (the method employed by Howard). However, in this case we computed the correlation separately for each observer; following Z-transformation, the average of these product-moment correlations was found to be .52. Since the average of the two judgments of each stimulus pair was used as the input to the INDSCAL analysis, it seemed appropriate to employ split-half correction techniques to estimate the reliability of judgment for the total test. Use of the Spearman-Brown prophecy formula (Guilford, 1965, p. 492) to do that correction yielded a reliability estimate of .68. Though this may be regarded as a reasonable level of reliability, it is clear that substantial error variance remained in the judgments of individual observers, a fact that must be considered in interpreting the SINDSCAL results.

How the reliability of the judgment of individual Sonar Technicians compared with that of Howard's sonar-naive observers must remain a question, since Howard did not report reliability data for individual participants. In the case of our listeners, a major factor responsible for the modest reliability obtained was the lack of discrimination in the distribution of judgments. We noted earlier our concern that experienced Sonar Technicians might judge many of the 8 stimuli to be "extremely different" from each other. Indeed, some participants assigned a scale value of 1 to numerous stimulus pairs. The average scale value assigned to all items across 28 listeners ranged from 1.73 to 5.00 with an overall mean of 2.81, which, in terms of the associated verbal descriptors, was not far from "Very Different" and is well below the arithmetic midpoint (4.0) of the response scale.

SINDSCAL Analysis

SINDSCAL is a computer program that implements the individual differences model for multi-dimensional scaling of judged differences among stimuli and is a modification of the more general INDSCAL program described by Chang and Carroll (1968). According to Prozansky (1975), the differences between SINDSCAL and INDSCAL lie mainly in the computational procedure and user options. The analysis determines, by an iterative least-squares procedure, the stimulus coordinates and the dimension weights that account for the maximum variance in matrices of scalar products derived from proximities data. It yields a group stimulus space, which is defined in a stimulus-by-dimensions coordinate matrix and a weights space, defined in a observers-by-dimensions matrix (Prozansky, 1975). The input matrix of similarities or distances is first converted to a matrix of scalar products. Then, to equalize each observer's influence on the analysis, these data are normalized by scaling each scalar product's matrix so that its sum of squares equals 1. The number of dimensions (minimum and maximum) is specified by the investigator, and it is necessary to determine empirically how many dimensions are appropriate for a given set of data.

Following the iterative procedure, the program prints out a dimension-by-observer's weights matrix and a dimensions-by-stimulus coordinates matrix. The approximate amount of variance accounted for by each dimension indicates the relative importance of each dimension to the solution. As noted earlier, a unique feature of the technique is that individual differences are preserved. The analysis produces both an overall group perceptual space, and a vector of saliency weights for each participant reflecting the relative importance of each dimension for that person (Howard, 1976).

Number of Underlying Dimensions

It was hypothesized that the similarity judgments of experienced Sonar Technicians might reflect a larger number of underlying perceptual dimensions than found by Howard with sonar-naive observers. One test of this hypothesis concerns the amount of variance in the similarity judgments accounted for by various numbers of perceptual dimensions. In Figure 2, a comparison of the variance accounted for in solutions having various numbers of dimensions is shown. It is evident that the amount of variance accounted for in the 3-dimensional solutions was virtually identical for Howard's and the current study, but beyond that point a small but systematically greater percentage of variance was accounted for in the judgments of the Sonar Technicians. In both studies, however, the amount of additional variance accounted for by solutions involving more than three dimensions was a markedly decreasing function. Partly for this reason, and partly because solutions of greater than three dimensions exceeded the recommended variance-accounted-for/degress-of-freedom ratio (Carroll and Chang, 1970), it was decided to limit the present analysis to a 3-dimensional solution. Since Howard also chose a 3-dimensional solution, and since there was so little difference between the two studies in the variance accounted for in the 3-dimensional solutions, this seemed in greatest accord with the objective of replicating Howard's results.

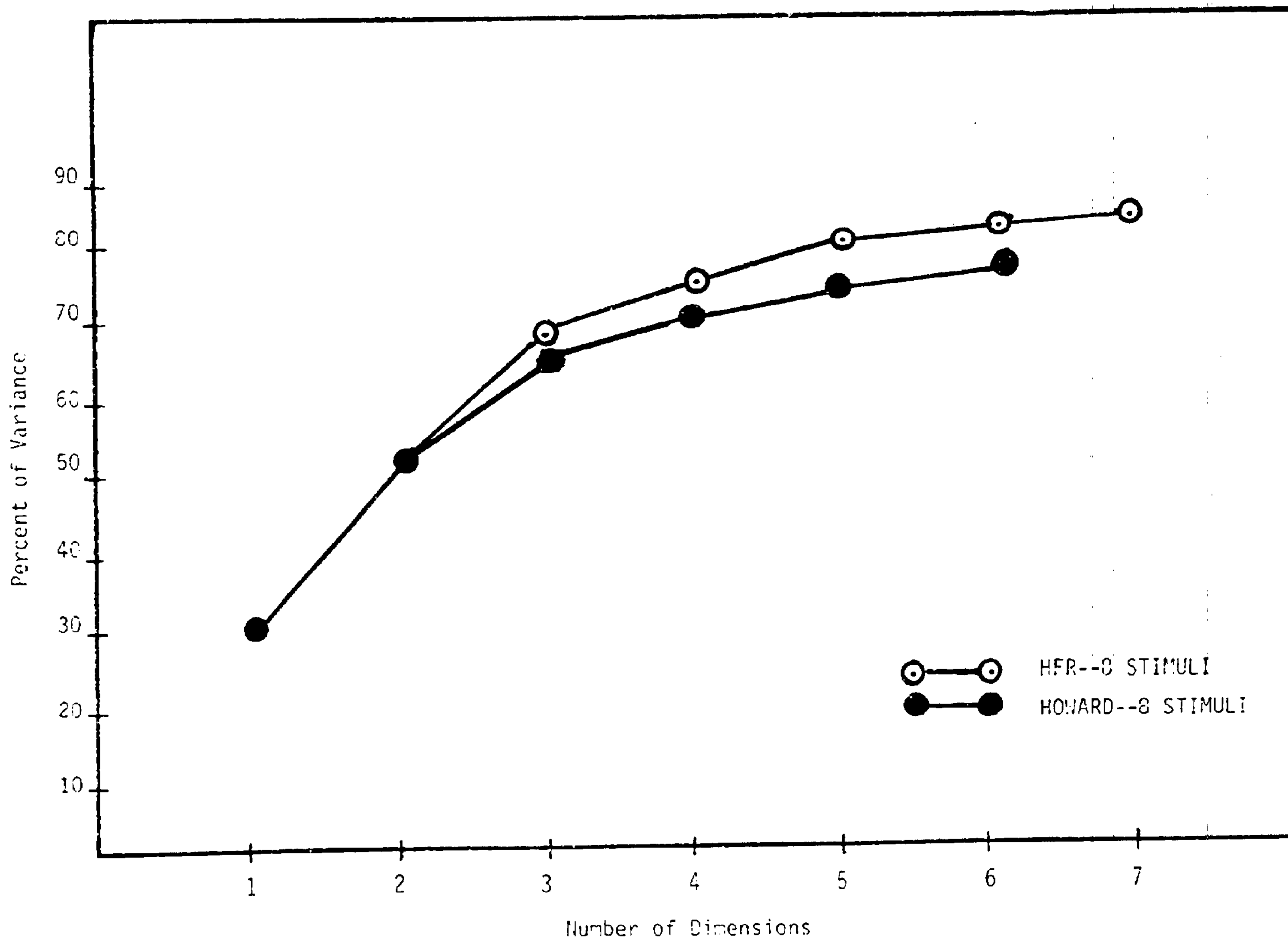


Figure 2. Percent variance accounted for (VAF) by INDSCAL solutions of varying dimensionality.

Correlation Between Human Factors Research (HFR) and Howard's Group Spaces

We sought to establish what relationship, if any, existed between HFR's and Howard's group spaces. This was done by computing Pearson product-moment correlations between stimulus coordinate values along dimensions of HFR's group space and stimulus coordinate values along dimensions of Howard's group space, for every pairing of the various coordinates. The results are shown in Table 1. It is evident from the correlations that HFR's first psychological dimension corresponds to Howard's first ($r = .82$, $p < .01$); HFR's second dimension corresponds to Howard's third ($r = .88$, $p < .001$); and HFR's third dimension corresponds to Howard's second dimension ($r = .85$, $p < .01$). Since the INDSCAL/SINDSCAL programs (hereafter referred to simply as "SINDSCAL") number their output dimensions by rank-ordering them according to "variance accounted for," the interchange of order in the second and third dimensions between HFR's and Howard's group spaces serves mainly to indicate a difference of importance (i.e., variance accounted for) of these dimensions in the two solutions. However, it is evident from the high correlations that the same perceptual dimensions are involved in both HFR's and Howard's 3-dimensional solutions. Thus, insofar as the _nature_ of the perceptual dimensions underlying the 8 stimuli (but not their perceived _importance_), Howard's results were replicated.

The correspondence between HFR's and Howard's group spaces is portrayed graphically in Figure 3. The figure presents a superposition of the 1-3 plane of Howard's group space upon the 1-2 plane of HFR's group space, with arrows drawn from the position of each stimulus in Howard's space to its position in HFR's space. A slight amount of

Table 1

Coordinate Values and Correlations Among Coordinates

For Howard's and HFR's 3-Dimensional Solutions

	HFR's 3-D Solution			Howard's 3-D Solution		
Dimension	ψ_1	ψ_2	ψ_3	ψ_1	ψ_2	ψ_3
Flutter	562	-209	552	567	504	-002
Sheet Cav.	-484	-363	-163	-326	-184	-526
Comp. Cav.	-213	-184	200	-376	-020	-419
Biologics	-382	542	514	-492	657	388
Torpedo	361	445	-279	-023	-202	311
Diesel	120	328	-475	110	-390	499
Rain Sq.	256	-149	-158	392	-079	-027
Steam	-219	-411	-190	148	-285	-226

.82*	-.19	-.10
.05	.23	.85*
.41	.88**	-.08

* $p < .01$

**$p < .001$

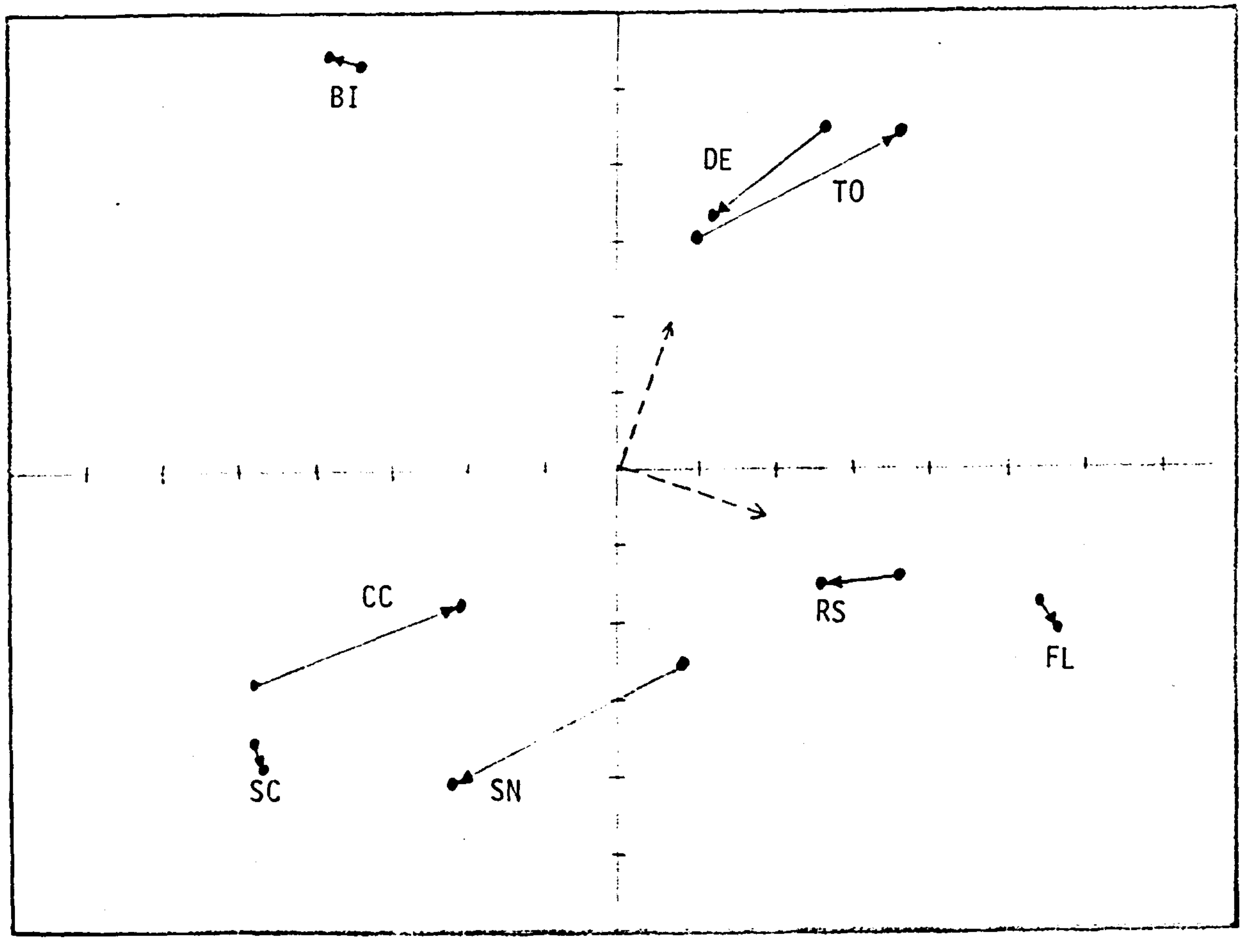


Figure 3. Superposition of Howard's 1-3 plane on HFR's 1-2 plane.

clockwise rotation is introduced in Howard's 1-3 plane (the axis directions of which are shown by dotted lines in Figure 3) to achieve a closer match between the two spaces. It can be seen that several of the stimuli correspond almost exactly (e.g., Sheet Cavitation, Biologics, and Flutter). Although the INDSCAL method yields solutions whose axes are uniquely oriented whenever the underlying model is applicable, the small amount of rotation between the two spaces depicted in Figure 3 should not bring the applicability of the model into question; this amount of rotation could easily be the result of experimental error. See, for example, Carroll and Chang (1970).

<u>Differences Between HFR's and Howard's Observer Spaces</u>

The high degree of correspondence between HFR's and Howard's group spaces seems to indicate that the same basic perceptual dimensions formed the basis of judgment for both Howard's and HFR's test participants. However, that is not to say that the different groups of listeners gave identical weightings or saliencies to these common dimensions in judging the degree of similarity among the stimuli. Indeed, at the very heart of the INDSCAL scaling method is the concept of differential weighting of the perceptual dimensions among individuals, and the scaling program provides for each participant a set of weights, or saliencies, which, in total, best account for the observed data. Therefore, if two or more groups of observers are represented in the same experiment, it is possible to determine whether, on the average, there are differences among those groups in terms of the saliencies, or importance, attached to the various perceptual dimensions.

The mean weights given each dimension by Howard's "musically inexperienced" observers, his "musically experienced" observers, and HFR's Sonar Technician listeners are shown in Figure 4. Howard (1976) showed that the differences in allocation of weight among dimensions between his two groups were statistically significant. No statistical test of the significance of differences among the three groups was made, since the similarity judgments of the three groups were not subjected to a combined INDSCAL analysis. However, given the high degree of correlation between Howard's and HFR's group spaces for this experiment, it seems to us highly probably that the evident differences in the way the Sonar Technicians weighted the dimensions are in fact significant. It is clear from Figure 4 that the Sonar Technicians attached greater salience, or importance, to our Dimension 2 (Howard's Dimension 3) than did either of the two groups of naive listeners. The Sonar Technicians, on the average, weighted our Dimensions 1 and 2 about equally, while giving Dimension 3 considerably less weight. This is in marked contrast to the musically experienced group of listeners, who gave our third dimension the greatest importance.

Regardless of the differences described above, it must be concluded that, in general, Howard's study was not only successfully replicated but with results that were remarkably similar considering the fact that the experimental observers were very dissimilar in their backgrounds, two totally different teams of research personnel were involved, and there were minor differences in experimental procedure, apparatus, and environment. While we were initially concerned about the reliability of the perceptual judgments of our listeners, the close

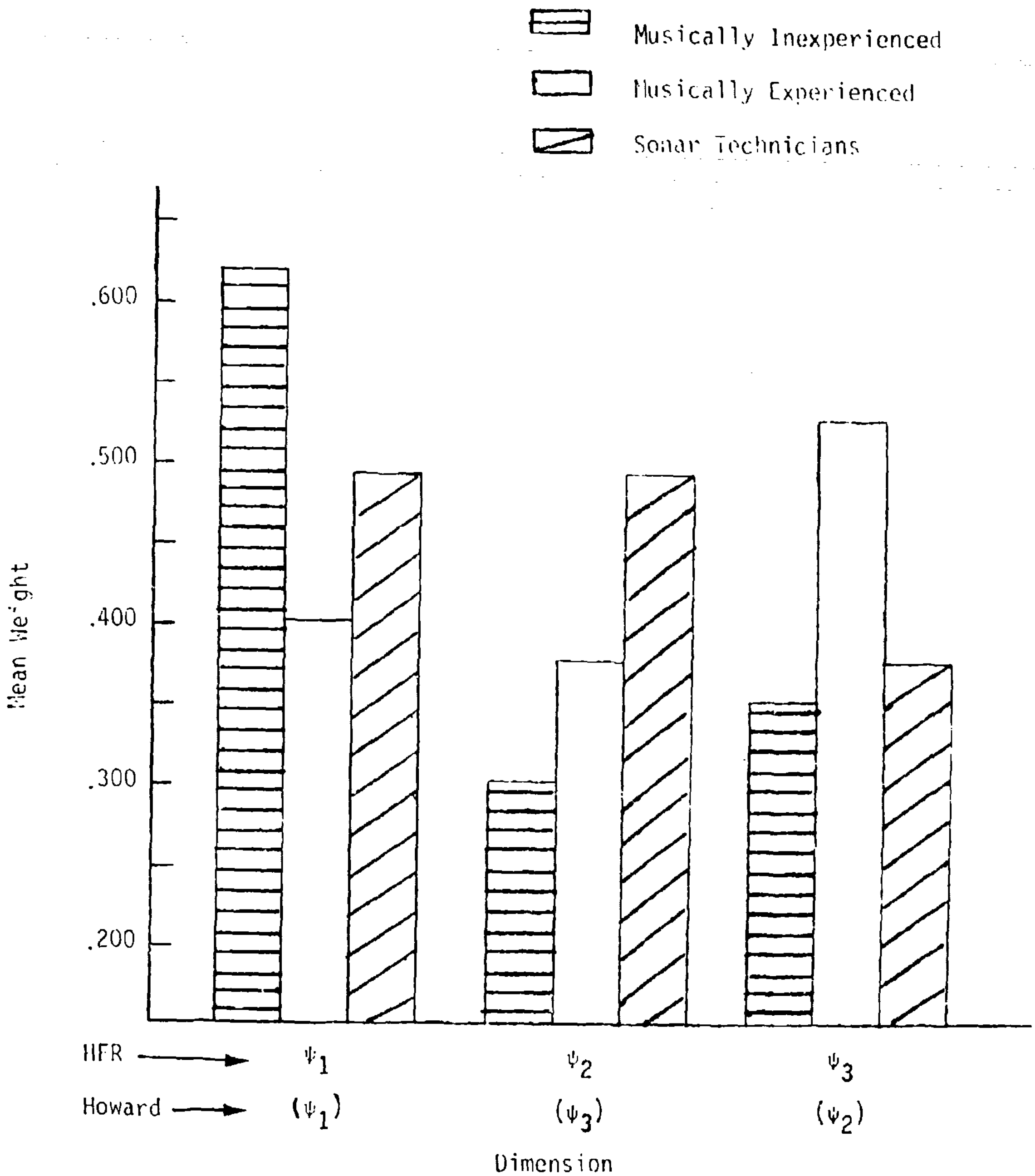


Figure 4. Comparison of weights given to each dimension by Sonar Technicians and by Howard's musically experienced/inexperienced observers.

correspondence with Howard's results seems to testify to the fact that this was not of serious concern. We also had some fear that the perceptual judgments of experienced Sonar Technicians might reflect criteria other than simple similarity or dissimilarity. While the differences in saliencies between our listeners and Howard's with respect to the three psychological dimensions underlying the perceptual space is testimony to the fact that professional experience did infuence saliency, the emergence of basically the three same psychological dimensions is testimony to the utility and reliability of the experimental approach and the SINDSCAL analysis procedure.

Interpretation of the Perceptual Dimensions

It will be evident from what follows that the interpretation of perceptual dimensions underlying the discrimination of complex sonar signals is no simple task. As is evident in Table 1, most of the 8 stimuli had substantial projections on at least two dimensions, suggesting that they are indeed complex. Further, because of their complexity, the reason why two or more stimuli shared, to some degree, something in common along a particular dimension was not always readily apparent.

The problem is illustrated by the first perceptual dimension which, although generally accounting for the most variance in the similarity judgments, is not easily interpreted from either Howard's analysis or our own. Howard regarded ψ_1 as distinguishing between stimuli that were relatively homogeneous versus those in which more than one sound was present. He related it to a steady state parameter, ϕ_1, which was defined by the tendency of some stimuli to have a bimodal spectrum. Biologics fell at one extreme (bimodal) of this dimension and Flutter fell at the opposite (unimodal) extreme.

An alternative to Howard's definition of this perceptual dimension is that ψ_1 is related to the modulation rate of the signal. Many sonar signals display periodic or aperiodic intensity modulation. Indeed, this is a key perception in the process of identifying the source of auditory sonar signals. The significant correlation between Howard's ψ_1 and HFR's ψ_1 suggests that whatever the underlying perceptual dimension, it was commonly perceived by both sonar-naive and sonar-experienced listeners. There are some notable differences, however, in the patterning of stimulus coordinates on the first dimension. The dominant stimulus in both analyses, Flutter, is clearly characterized by pronounced rapid intensity modulation (beats). However, Torpedo had a large positive coordinate value in HFR's solution but not Howard's. This stimulus was characterized by rapid but weak beats that might more likely be perceived by experienced sonar personnel than by naive observers. In contrast, stimuli that have negative projections on this dimension are characterized by slow and sometimes irregular beat rates in both solutions. This is particularly true of Biologics which had the most negative coordinate value projection in Howard's analysis and the next to lowest in our own. Compressed Cavitation, which also had negative projections in both solutions, similarly had a slow but pronounced beat. Sheet Cavitation, which fell at the extreme in our solution, has a very weak beat whose frequency is difficult to perceive. Finally, stimuli having intermediate values on this dimension lack perceptually clear modulation. We are inclined to identify this first dimension as BEAT RATE, a characteristic of sonar signals that is of particular operational significance.

The second psychological dimension in Howard's analysis, which corresponds to our third, was described by Howard as "presence versus absence of low frequency periodicity." The dominant stimulus in Howard's analysis was Biologics, which is characterized by pronounced but irregular modulation (it had the second strongest projection in our solution). A second stimulus with a strong positive projection on this dimension in both analyses was Flutter, which also has a pronounced modulation though it is more regular. These signals appear together on Howard's ψ_2 and our ψ_3, whereas they were separated from each other on ψ_1. Both signals are also characterized by a complex background of broadband sound described by both "hiss" and "roar."

At the opposite extreme, the principal stimulus is Diesel and, to a lesser extent, Torpedo. Diesel clearly lacks intensity modulation, although some observers detect weak modulation in Torpedo. Both of these stimuli are also characterized by clearly perceptible tonality, but this is also true of Flutter, so tonality does not appear to be the basis for their commonality on this dimension. Rather, it seems that the presence of discernible modulation is again a factor, but, in this case, the discrimination is between stimuli that do or do not have a recognizable periodicity whereas, in both analyses, ψ_1 discriminated among stimuli by having very different modulation rates. Thus, we have tentatively called this dimension BEAT CLARITY, a description in general accord with Howard's.

Howard's third psycholcgical dimension, corresponding to our ψ_2, was described as the degree to which the stimulus was characterized by "tinniness" or the relative amount of high frequency energy. The strong projections of Sheet Cavitation and Compressed Cavitation in Howard's analysis, and Sheet Cavitation together with Steam in our analysis, reflect stimuli that have strong broadband components and very weak or no narrowband components. In contrast, stimuli that had projections at the opposite extreme, particularly Diesel and Torpedo in both Howard's and our analyses, have a discernible narrowband or tonal character in addition to their broadband characteristics. Some people also attribute a tonal character to Biologics which may account for its appearance with the tonal stimuli in both analyses. Thus, we are inclined to endorse Howard's label of "tinniness," though Biologics does not seem to fit well and have labeled this dimension TONALITY.

While these interpretations are somewhat tenuous and unsatisfying, no further attempt to rationalize them is made here, since it was our expectation that the nature of the underlying dimensions might be clarified in the second experiment which involved a substantially larger number of stimuli. It was hoped that, by including several stimuli from each of several classes of targets, the nature of the underlying dimensions on which they were discriminated in perceptual space might become clearer.

On the basis of the replication experiment, however, it was concluded that:

1. The number and nature of the perceptual dimensions underlying the similarity judgments of a limited set of diverse sonar signals was essentially the same for experienced Sonar Technicians as it was for observers who were naive with respect to sonar signal interpretation
2. Experienced Sonar Technicians do use different saliencies in judging the differences among sonar signals from those used by naive personnel.
3. BEAT RATE, BEAT CLARITY, and signal TONALITY are three likely descriptions of the dimensions of the group perceptual space underlying judgments of similarity of sonar signals.

EXPERIMENT 2: INVESTIGATION OF A LARGER STIMULUS SET AND THE RELATIONSHIP OF PERCEPTUAL DIMENSIONS TO TARGET CLASSIFICATION

Despite the perhaps remarkable similarities between the results of Experiment 1 and the earlier work of Howard, a number of questions remained:

1. Does the perceptual dimensionality of the discrimination space change when a larger, more operationally representative sample of recorded sonar stimuli is employed?
2. How do the target classification judgments and target class conceptual stereotypes of Sonar Technicians relate to the underlying perceptual dimensions?
3. Can the physical dimensions underlying the perceptual dimensions be more completely identified than proved possible with the one-third octave band analysis employed by Howard?

Procedure

Experimental Stimuli

The selection of stimuli to serve the objectives of Experiment 2 necessitated a difficult compromise between the diversity of stimuli to be employed and the amount of overlap desired in the stimulus sets used in Experiments 1 and 2. Though it would have been desirable to use a very large number of stimuli, the requirement to judge the similarity of all pairs of stimuli, required by the INDSCAL approach to multi-dimensional scaling, places a severe practical limit on the number of stimuli that can reasonably be employed. Based on a consideration of the amount of time that experienced Sonar Technicians would be able to devote to the experiment, as well as possible adverse effects of the tediousness of the experimental task, it was decided that the maximum allowable number of stimuli that could be used was 14. This generated 91 pairs of stimulus presentations meaning that, with each pair presented twice, a total of 182 judgments was required.

Having decided on an upper limit for the number of stimuli, the remaining problem was to select, from a very large pool of target signals, a sample that would be as representative as possible of the discrimination tasks faced by Sonar Technicians in the operational environment. It was noted earlier that these personnel are required to classify auditory sonar signals into five broad classes:

1. Submarine
2. Surface warship
3. Cargo ship
4. Light craft
5. Natural phenomena, including sea life and weather effects.

The problem was to select 14 stimuli in such a way that each target class would have enough representation so that the dimensions and/or saliencies responsible for classification judgments might be identified. Since there is considerable diversity in the nature of the target signals generated by targets of the same class, it was felt that more than one signal from each class must be included in the set. In addition, it was desired to have some overlap in the stimulus sets used in Experiments 1 and 2 so that possible similarities in the dimensions emerging from the two experiments could be identified. With these constraints in mind, it was decided that several signals from each major target class should comprise the stimulus set. With the assistance of Navy personnel, recorded signals from 3 submarines, 3 surface warships, 3 cargo ships, and 2 light craft were selected from a tape library and reproduced. In making these selections, care was taken to represent variations within each target class that significantly affect the auditory stimulus, namely, the sound sources involved and the target's operating speed.

The problem remained of selecting 3 additional stimuli from Howard's original set of 8 which would provide for some degree of overlap in the two stimulus sets. Greater overlap was not possible because several of Howard's stimuli represented natural phenomena which we had decided to exclude because of their low operational significance. (This is not to say, of course, that signals generated by natural phenomena might not involve perceptual dimensions different from those involved in discriminating among man-made objects, though the likelihood of this seemed low.) Also, several of Howard's stimuli were of uncertain origin, that is, they could have been generated by more than one class of target, and it was not possible to positively identify their source. In the final analysis, it was decided to select stimuli that were known to be from the domain of the four operationally significant target classes and which, in Howard's study, had shown strong projections on one or more of his perceptual dimensions. Using these criteria, Flutter, Sheet Cavitation, and Compressed Cavitation were selected to round out the set of 14 stimuli for Experiment 2.

Presentation Format

The 14 recorded stimuli were prepared in 3 formats for meeting the various experimental objectives:

1. All possible pairs of 14 target sounds were prepared in the same format as used in Experiment 1. They were assembled in an order dictated by a table of random numbers, first into a group of 91 items where stimulus i preceded stimulus j and then into a second set of 91 items where stimulus j preceded stimulus i. These items comprised the stimuli for Task 1 which required similarity judgments of each stimulus pair as in Experiment 1.
2. A 6-second recording of each of the 14 stimuli was prepared for use in Task 2 which required the participants to judge the similarity of each stimulus to their conceptual stereotype of each of the four operational target classes. The 6-second duration was selected for two reasons: (1) it was long enough to equalize the time of exposure to each stimulus between Tasks 1 and 2; and (2) it was short enough to preclude formation of more than a very quick first impression of the target's class. (It was desirable to keep the focus on perceptual rather than cognitive responses, and previous research (Mecherikoff, 1974) had shown that Sonar Technicians typically take considerably longer than 6 seconds to perform a "nature of sound" classification analysis.)
3. A 30-second recording of each of the 14 signals was prepared for presentation as a more conventional target classification

task. Task 3 permitted a considerably more complex response than Task 2, since it provided sufficient time for the Sonar Technicians to employ the analysis techniques that they typically use in classifiying sounds. The purpose of this task was to provide an opportunity for relating classification judgments, including classification errors, to the positions occupied by the various stimuli in the underlying perceptual space.

Observers

The observers were the same 26 experienced Sonar Technicians who participated in Experiment 1.

Test Administration

Task 1 was administered in 2 parts with a rest break of 10 minutes after presentation of approximately half of all stimulus pairings. The same graphic response scale for recording judgments of similarity and difference was used as in Experiment 1.

Task 2 required a judgment of the similarity of each stimulus to each listener's conceptual stereotype of the four operational target classes. To accomplish this, the 14 stimuli were presented 4 times, each time in a different random order. On the first occasion, the listeners judged the degree to which each stimulus resembled their concept of what a submarine target sounded like; on the second occasion, they judged how closely each stimulus resembled their concept of a surface warship; on the third, how closely each resembled a cargo ship; and, on the fourth, how closely each stimulus resembled a light craft. An example of the response form is shown in Figure 5. Again, a

TEST C

Please judge each of the following signals on

how similar it sounds to a typical SUBMARINE signal:

Signal:							
1.	1	2	3	4	5	6	7
	Nothing like a SUB			Some SUB-like qualities			Very strongly resembles SUB
2.	1	2	3	4	5	6	7
3.	1	2	3	4	5	6	7
4.	1	2	3	4	5	6	7
5.	1	2	3	4	5	6	7
6.	1	2	3	4	5	6	7
7.	1	2	3	4	5	6	7
8.	1	2	3	4	5	6	7
9.	1	2	3	4	5	6	7
10.	1	2	3	4	5	6	7

Figure 5. Response form for recording judgments of stimulus similarity to a conceptual stereotype.

7-point scale was used. This task was administered following a 10 minute break subsequent to the completion of Task 1.

Task 3 required the observers to classify each stimulus into one of the four operational categories, or, if they felt it did not belong to any of those categories, they were to classify it as "other." This task was always administered last so that the observer's memory for the classification of a particular stimulus would not have any impact upon the perceptual discriminations called for by Tasks 1 and 2.

The experimental setting for all three tasks and the tape recorders and headphones employed were identical to those used for Experiment 1.

Results

Reliability of Classification Stereotypes

To assess the role of conceptual stereotypes in the classification judgments of Sonar Technicians, it was necessary to establish that they agreed on what constituted each stereotype. That is, it was necessary to demonstrate that Sonar Technicians agree, in general, concerning the types of sounds generated by various stereotypes. It was assumed that such agreement would be demonstrated if the judgments of different Sonar Technicians correlated highly with one another concerning the resemblance of different target stimuli to the several target class concepts. Thus, the average similarity score of each stimulus to each target class assigned by the 11 observers from the Submarine Training Center was correlated with that assigned by the 15 observers from the ASW Training Center. The scores were rank-ordered for each group of observers, and the agreement among ranks was computed using the Spearman rank-difference correlation coefficient. The results are shown in Table 2. It is evident that the listeners generally agreed with one another concerning the degree to which each stimulus resembled a particular target class. The agreement was strongest for cargo ships and light craft which is believed to be a reflection of the saliency of certain auditory clues associated with those classes during training. Agreement was less substantial for submarine and warship classes, a result that appears in accord with earlier studies (Mackie, et al., 1968; Mecherikoff, 1974) in which it was found that more classification errors are made for submarines and warships, in general, than for cargo ships and light craft. Over all, it must be concluded that the Sonar Technicians largely agreed, on the basis of whatever criteria they might have used, concerning which stimuli most closely resembled which target class stereotypes.

Stereotype Resemblance and Classification Accuracy

The fact that Sonar Technicians agree upon stereotypical resemblance does not necessarily mean that the stereotype has been "correctly" defined. Ideally, that definition would correspond closely with the signal patterns typically generated by targets of a given class. As Mecherikoff (1974) noted, the signal from any particular target may more or less resemble the stereotype of the class to which it actually belongs. Given this state of affairs, it was of interest to determine, for each of the 14 stimuli used in Experiment 2, how strongly it resembled one or more target class stereotypes and whether

Table 2

Interjudge Agreement Concerning the Resemblance of 14 Stimuli to 4 Target Class Stereotypes (N = 26)

Target Class	Coefficient of Agreement (ρ)
Cargo Ship	.96
Light Craft	.95
Submarine	.73
Warship	.66

the degree of similarity was related to the classification judgment for that stimulus. The results of this analysis are shown in Table 3. Several things are worthy of note. First of all, it is evident that few of the 14 stimuli resembled any particular class stereotype exclusively. In cases where that resemblance was very strong, e.g., stimuli 5, 7, and 11, the stereotypical judgment dominated the classification judgment, usually with good results. In some cases, the stereotypical judgment was incorrect, and this usally led to poor classification results (note particularly stimuli 12 and 14 which were correctly classified by only 15 percent and 12 percent of the observers, respectively). The classifications of three stimuli in Table 3 were uncertain since these were from Howard's original set of signals whose origins were not identified.

In general, it may be concluded from these results that:

1. Relatively few members of the stimulus set closely resembled only a single target class.
2. Sonar Technicians in general classify targets in accord with the degree to which they resemble personally-held conceptual stereotypes, whatever the basis for those stereotypes may be. However, as noted earlier, there is considerable agreement among Sonar Technicians in this regard.

SINDSCAL Analyses

Scale values representing the judged similarity of all pairs of stimuli were derived from the response sheets, as before, for both Tasks 1 and 2. Using these data, two SINDSCAL analyses were

Table 3

Average Similarity Ratings of 14 Stimuli to 4 Target Class Conceptual Stereotypes

[Scaled from 1 (low) to 7 (high)] (N = 26)

Stimulus	Actual Target Type	Judged Similarity to Each Target Class Stereotype				Percent Correctly Classified	Percent Classifications in Agreement With	
		Submarine	Cargo Ship	Warship	Light Craft		Most Dominant Stereotype	2nd Most Dominant Stereotype
1	Cargo Ship	2.2	5.6	5.1	2.0	53	58	38
2	Flutter	3.3	2.5	3.4	5.0	Source Uncertain	65	--
3	Sheet Cav	4.5	2.2	3.1	4.2	"	42	8
4	Comp Cav	4.3	4.3	2.7	1.5	"	58 (Sub)	38 (Cargo Ship)
5	Sub(E)	6.2	1.1	1.0	3.6	96	96	--
6	Sub(F)	4.3	4.5	3.7	2.0	19	54*	19
7	Sub(G)	6.1	2.7	2.5	1.5	96	96	--
8	Warship(H)	3.0	3.7	3.8	2.2	81	81	8
9	Warship(I)	3.7	2.0	3.5	4.5	23	50*	23
10	Warship(J)	3.2	3.5	3.9	3.0	42	42	19
11	Cargo Ship(K)	1.5	6.4	3.3	1.2	85	85	--
12	Cargo Ship(L)	2.2	2.8	3.8	5.1	15	73*	12
13	Lt Craft(M)	4.0	3.4	4.2	2.9	38	42*	4
14	Lt Craft(N)	3.5	4.8	4.5	2.7	12	27*	46

*Dominant stereotypes that were incorrect.

performed: (1) an analysis based on the similarity ratings of each of the 91 pairs of stimuli in Task 1, averaged over the two presentations, hereafter referred to as SINDSCAL 14; (2) an analysis incorporating, in addition to the judgments of similarity between the 91 pairs of stimuli, the judgments of similarity of each stimulus to each observer's conceptual stereotype of each of the 4 major target classes. This analysis is hereafter referred to as SINDSCAL 18. In this latter analysis, it was necessary to enter estimated values reflecting the hypothetical similarity of each pair of conceptual stereotypes to each other. (The Sonar Technicians were not asked to perform this task and indeed they might have had some difficulty in dealing with this abstract notion.) Two sets of estimates were used and the results compared in two separate SINDSCAL 18 analyses: Estimate (A) in which each pair of conceptual stereotypes was treated as equally distant (a scale value of 5, "moderate dissimilarity" was used) and Estimate (B) in which variable scale values ranging from 3 to 7 were used which reflected the judgments of one highly experienced Sonar Technician (see Table 4). Since these values involved only 6 out of a total matrix of 159 pairs of stimulus comparisons, it was expected that the impact of these estimates would be rather small in defining the total perceptual space.

Selection of Dimensionality

In employing the INDSCAL scaling technique (and most other multidimensional scaling techniques), the investigator is faced with choosing a solution of appropriate dimensionality for representing the results. This is generally not a clearcut issue. The decision is

Table 4

Variable Estimates of Similarity of Conceptual

Stereotypes Used for Solution "B"

	Submarine	Cargo Ship	Warship	Light Craft
Submarine	---			
Cargo Ship	7.0	---		
Warship	5.0	2.0	---	
Light Craft	5.0	5.0	3.0	---

usually simpler in cases where the stimuli are synthesized from a small number of distinct physical characteristics. In such cases, it is often reasonable to choose an INDSCAL solution of dimensionality equivalent to that of the underlying physical stimulus space. However, in the case of stimuli as complex as sonar signals, the number of relevant dimensions required to describe the physical attributes of the stimuli is not evident, and, therefore, little guidance is available from that quarter regarding the selection of an appropriately dimensioned INDSCAL solution space.

What criteria should be applied, then, to select an appropriate dimensionality? In the ideal (error-free) case, all of the variance in the data would be accounted for in a finite (hopefully small) number of dimensions; adding further dimensions to the solution space could add nothing in terms of "variance accounted for" (VAF).

Of course, in any experiment involving human judgment, there will be error variance, and one cannot expect to have 100 percent of the variance accounted for by the INDSCAL model with <u>any</u> meaningful number of dimensions. What must be examined is the variation of VAF as a function of the dimensionality of the INDSCAL solution. In the general case, it is to be hoped that solutions of small dimensionality will account for large percentages of total variance, with solutions of increasingly large dimensionality adding very little to total VAF. This sort of outcome suggests that the first few dimensions provide some parsimonious and meaningful description of the underlying perceptual space, with added dimensions only accounting for "error" variance.

Figure 6 shows percentage of variance accounted for by SINDSCAL solutions of varying dimensionality for each of the four analyses discussed in this report. The 8-stimuli experiments, wherein solutions utilizing 3-dimensions were chosen, were discussed earlier. Howard (1976) elected to present his results as 3-dimensional solutions, so we did the same for our replication experiment. From a consideration of Figure 6, it appears that Howard's selection was a reasonable one. There seems to be a "break" in the 8-stimuli curves at 3-dimensions; the employment of greater than 3-dimensions gives diminishing returns in terms of variance accounted for, and the assumption is probably justified that, beyond 3-dimensions, it is most likely error variance that is being accounted for.

However, the curves for the SINDSCAL 14 and SINDSCAL 18 analyses are notably different from the 8-stimuli experiments. First of all, there is no evident "break point" in the curves, which might distinguish a point of diminishing returns. Thus, the choice of dimensionality for SINDSCAL 14 and SINDSCAL 18 is made more difficult. Second, there is evidently less variance accounted for by increased solution dimensionality. This brings into question the "quality" of these solutions. The 14-stimuli and 18-stimuli analyses had many more stimulus-pairings to be accounted for and, therefore, many more opportunities for error to enter into the data. On the other hand, increasing the dimensionality of the solution gives the SINDSCAL algorithms more degrees of freedom to account for <u>both</u> "systematic" and "error" variance. Thus, the issue of solution "quality" is affected both by the nature of the data and the dimensionality of the solution.

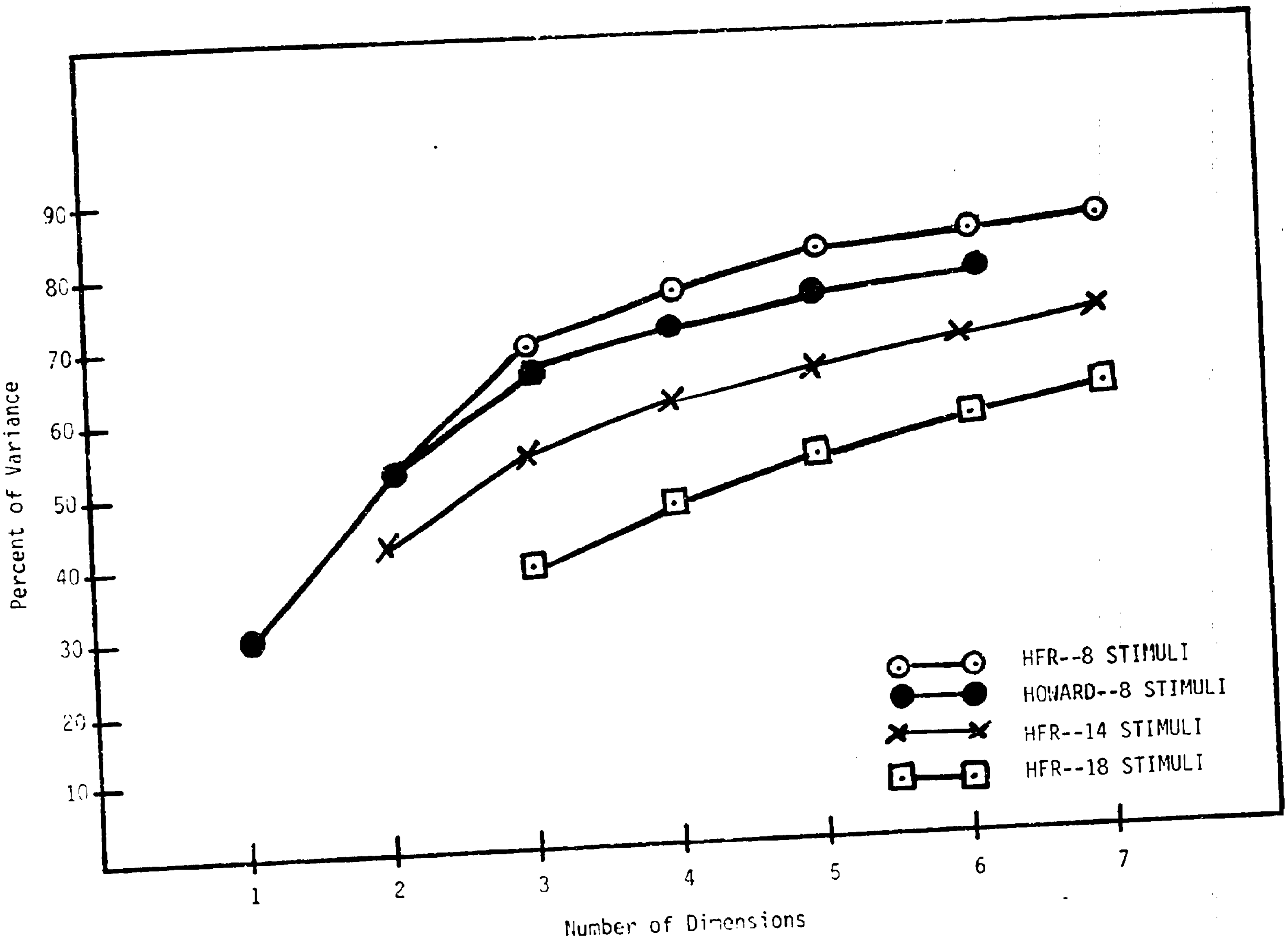


Figure 6. Percent variance accounted for (VAF) by INDSCAL solutions of varying dimensionality.

Carroll and Chang (1970) developed a measure of solution quality which might be summarized in the following way. Even with totally random data, the INDSCAL scaling method can be expected to account for some proportion of total variance, and that proportion is expected to vary directly according to the number of degrees of freedom in the solution and inversely according to the number of degrees of freedom in the data. Carroll and Chang show how to calculate the number of degrees of freedom in both the solution and in the data and suggest that the ratio of these two numbers (which they call the "degrees of freedom ratio") may be used to provide an estimate of "chance" variance accounted for. On the basis of Monte Carlo experiments, they suggest as a criterion that the variance accounted for in any solution should be at least five times as great as the "degrees of freedom ratio."

In Figure 7, variance accounted for is expressed in units of the appropriate degrees of freedom ratio (i.e., VAF divided by DF ratio) for SINDSCAL solutions of varying dimensionality for each of the four analyses. It may be seen immediately that for solutions involving more than 3-dimensions, the VAF/DF ratio for the 8-stimuli experiments falls below the minimum acceptable level recommended by Carroll and Chang. This reinforces the prior choice of using three dimensions for analyzing the 8-stimuli data. It is also evident in Figure 7 that by Carroll and Chang's criterion, all the solutions for the SINDSCAL 14 and SINDSCAL 18 analyses are superior to those of the 8-stimuli experiments, and all of them exceed the minimum acceptable level. Thus, it appears that the 14- and 18-stimuli solutions are of adequate "quality."

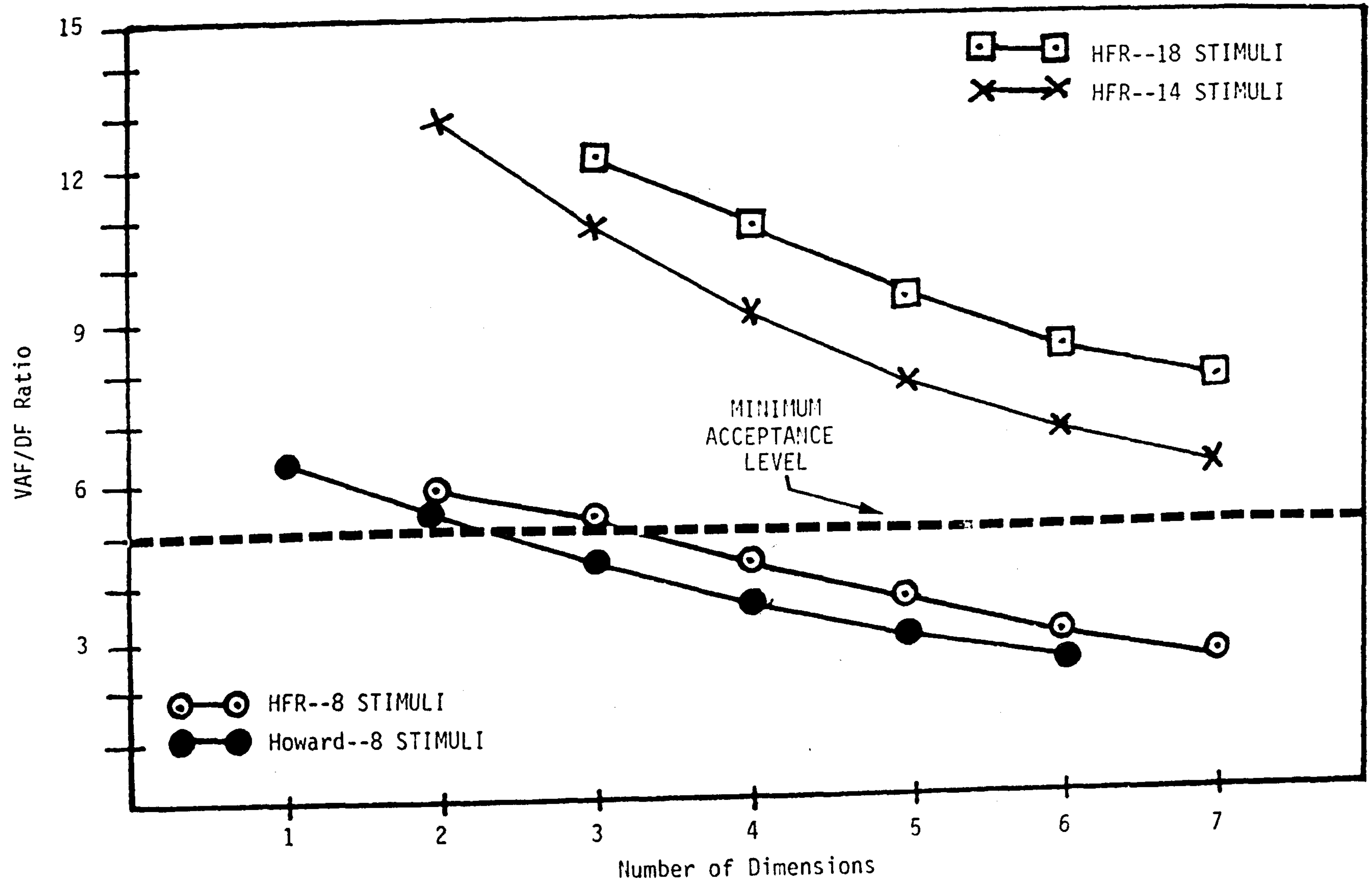


Figure 7. VAF/DF ratios for various SINDSCAL solutions.

On the other hand, the quality of the solutions for SINDSCAL 14 and 18 is seen to drop fairly sharply with increasing dimensionality, so caution is warranted in the employment of higher dimensional solutions. Caution is further in order because Carroll and Chang's Monte Carlo analysis did not involve combinations of solution and data parameters closely approximating those of the 14- and 18-stimuli experiments. Therefore, in attempting to interpret the nature of the perceptual space, we have examined INDSCAL solutions of either 4- or 5-dimensions, which seems defensible in view of the results of Figure 7.

Results of SINDSCAL 14

Based on the considerations previously outlined, both the 4- and 5-dimensional solutions for SINDSCAL 14 were examined for interpretability of the underlying perceptual dimensions. Neither solution was fully satisfying in this regard (see Tables 5 and 6), but some reasonably interpretable dimensions did emerge. The question of how many dimensions can be defended on the basis of perceptual interpretability will be deferred until the results of the SINDSCAL 18 analysis are presented, because those results are, in some respects, clearer.

Beat Clarity

ψ_1 in the 4-dimensional solution and ψ_1 in the 5-dimensional solution are clearly the same dimension (ρ = .99), and have strong projections by Cargo Ship (L), Flutter (B) and Cargo Ship (A). Each of these stimuli is characterized by a pronounced rapid beat rate while, at the opposite extreme of ψ_1, Submarine (F), Light Craft (M) and Warships (I) and (J) are characterized by very weak, barely discernible

Table 5

SINDSCAL 14

Four Dimensional Solution

ψ_1		ψ_2		ψ_3		ψ_4	
Submarine (F)	366	Cargo Ship (K)	597	Sheet Cav. (C)	315	Flutter (B)	379
Light Craft (M)	332	Warship (J)	342	Warship (H)	281	Warship (H)	311
Warship (I)	267	Light Craft (N)	226	Cargo Ship (L)	260	Cargo Ship (L)	246
Warship (J)	226	Warship (H)	169	Warship (I)	258	Submarine (F)	244
Comp. Cav. (D)	197	Light Craft (M)	109	Cargo Ship (A)	182	Submarine (G)	208
Light Craft (N)	133	Submarine (F)	032	Light Craft (N)	170	Light Craft (M)	208
Sheet Cav. (C)	111			Light Craft (M)	072	Light Craft (N)	122
Submarine (G)	039			Submarine (F)	029		
Cargo Ship (K)	-122	Cargo Ship (L)	-015	Warship (J)	-026	Cargo Ship (A)	-059
Submarine (E)	-142	Flutter (B)	-069	Comp. Cav. (D)	-108	Comp. Cav. (D)	-122
Warship (H)	-216	Comp. Cav. (D)	-071	Flutter (B)	-129	Warship (J)	-195
Flutter (B)	-341	Cargo Ship (A)	-117	Submarine (E)	-364	Warship (I)	-244
Cargo Ship (A)	-385	Warship (I)	-143	Cargo Ship (K)	-384	Submarine (E)	-253
Cargo Ship (L)	-465	Sheet Cav. (C)	-290	Submarine (G)	-557	Cargo Ship (K)	-390
		Submarine (G)	-332			Sheet Cav. (C)	-454
		Submarine (E)	-441				
Variance Accounted for	24.3%	Variance Accounted for	13.9%	Variance Accounted for	11.1%	Variance Accounted for	9.1%

Total Variance Accounted for: 59.4%

NOTE: The sum of squares on each dimension of the stimulus space is normalized to unity so "variance accounted for" may be seen in the group space (Carroll and Chang, 1970, p. 289).

Table 6

SINDSCAL 14

Five Dimensional Solution

ψ_1		ψ_2		ψ_3		ψ_4		ψ_5	
Submarine (F)	380	Cargo Ship (K)	609	Sheet Cav. (C)	329	Flutter (B)	335	Submarine (G)	478
Light Craft (M)	315	Warship (J)	289	Warship (H)	289	Warship (H)	321	Submarine (E)	455
Warship (I)	210	Light Craft (N)	287	Warship (I)	247	Submarine (F)	255	Cargo Ship (A)	440
Warship (J)	202	Warship (H)	211	Cargo Ship (L)	246	Submarine (G)	241	Sheet Cav. (C)	141
Light Craft (N)	156	Cargo Ship (A)	070	Cargo Ship (A)	240	Cargo Ship (L)	234	Cargo Ship (L)	001
Comp. Cav. (D)	136	Light Craft (M)	065	Light Craft (N)	185	Light Craft (M)	196		
Sheet Cav. (C)	124	Submarine (F)	040	Light Craft (M)	058	Light Craft (N)	138	Warship (H)	-013
Submarine (G)	108			Submarine (F)	037			Light Craft (N)	-043
		Cargo Ship (L)	-043			Cargo Ship (A)	-016	Submarine (F)	-075
Submarine (E)	-104	Submarine (G)	-177	Warship (J)	-048	Comp. Cav. (D)	-154	Warship (I)	-133
Cargo Ship (K)	-126	Warship (I)	-219	Comp. Cav. (D)	-156	Warship (J)	-211	Cargo Ship (K)	-193
Warship (H)	-210	Flutter (B)	-243	Flutter (B)	-191	Submarine (E)	-240	Light Craft (M)	-215
Cargo Ship (A)	-320	Comp. Cav. (D)	-270	Submarine (E)	-337	Warship (I)	-256	Flutter (E)	-226
Flutter (B)	-416	Sheet Cav. (C)	-274	Cargo Ship (K)	-393	Cargo Ship (K)	-398	Warship (J)	-295
Cargo Ship (L)	-489	Submarine (E)	-345	Submarine (G)	-508	Sheet Cav. (C)	-446	Comp. Cav. (D)	-323
Variance Accounted for	24.3%	Variance Accounted for	11.2%	Variance Accounted for	10.6%	Variance Accounted for	9.5%	Variance Accounted for	8.1%

beats.[3] The dominant characteristic of this dimension does not appear to be the rapidity of the beats, since Light Craft (M) and Submarine (F) both have rapid beats. Rather, the distinguishing characteristic is more likely beat strength or clarity, and we have tentatively labeled ψ_1 as BEAT CLARITY. It will be recalled that BEAT CLARITY was also identified as a dimension in Experiment 1. It is a very important dimension in the present solution, accounting for 24 percent of the variance in the similarity judgments.

Beat Tonality

ψ_2 in the 4-dimensional solution and ψ_2 in the 5-dimensional solution, which correlate .86, appear to reflect the same underlying perceptual dimension. Cargo Ship (K) which shows a very strong projection on this dimension has a particularly dominant pulsed-tone quality. Warship (J), Light Craft (N), and Warship (H) have perceptible tones and some pulsing, though in these stimuli the tone appears more in the background. At the opposite extreme of this dimension, Submarine (E), Submarine (G), and Sheet Cavitation (C) all lack tonal quality though, as we shall see, the two submarine signals are characterized by a predominant "squeakiness." In addition, each of the stimuli at the opposite end of this dimension is characterized by a broadband atonal "hiss." Because of the dominance of Cargo Ship (K) on this dimension and the absence of tonality among stimuli having opposite projections on this dimension, we are inclined to label ψ_2 as BEAT TONALITY. This dimension, which accounted for 11-14 percent of the variance in the two solutions, did not appear in

[3]For elaboration of the perceptual characteristics of each stimulus, see Physical and Psychological Description of the Stimuli, p. 86 ff.

Experiment 1. Rather, in that case, an unmodulated tonal dimension was identified which was associated with two stimuli not included in SINDSCAL 14--DIESEL and TORPEDO.

Squeaky Beats

ψ_3 in both the 4- and 5-dimensional solutions was most strongly defined by Submarine (G), Cargo Ship (K), and Submarine (E) at the one extreme and by Sheet Cavitation (C) at the other. The correlation between the stimulus projections was .99. Submarines (G) and (E) are both characterized by periodic squeaks or cranking sounds and, as noted earlier, (K) has strong tonal pulsing. In contrast, Sheet Cavitation (C) which appears at the opposite extreme of ψ_3, has neither tonality nor pulsing. Thus, ψ_3, which appears to be quite important in recognizing submarine targets, has been tentatively labeled SQUEAKY BEATS. This dimension, which accounted for about 11 percent of the variance, did not appear in Experiment 1.

Beat Rate

ψ_4 in both solutions is dominated by Flutter (B) and Warship (H) at one extreme and Sheet Cavitation (C) and Cargo Ship (K) at the opposite extreme (ρ = .98). Flutter (B) is characterized by very rapid metallic sounding beats, while Warship (H) has a distinct periodic "thump," as well as rapid less-intense beats. Tonality probably can be ruled out in defining this dimension, since the stimuli at both extremes have some tonal character. Rather, we are inclined to view this dimension as BEAT RATE since Cargo Ship (K) had one of the slowest beat rates in the stimulus set. A possible complication in this interpretation is the joint appearance of Sheet Cavitation (C) and

Cargo (K). The beat of Sheet Cavitation was so weak that its rate was not determinable. Be that as it may, BEAT RATE was identified as a dimension of Experiment 1 and is of undoubted importance in target classification. This dimension accounted for about 9 percent of the variance in the similarity judgments.

Dual Beats

ψ_5 in the 5-dimensional solution is strongly dominated by Submarine (G), Submarine (E), and Cargo Ship (A), which have in common a rapid beat superimposed on a slower beat pattern. That is, there are two discernible beat-rates. This is not true of the stimuli at the opposite end of this dimension; i.e., Compressed Cavitation (D), Warship (J), Flutter (B), and Light Craft (M). We saw earlier that Submarine (E) and Submarine (G) defined the Squeaky Beat dimension. However, Cargo Ship (A) does not belong in company with Submarines (E) and (G) in that regard. Cargo Ship (A), instead, is characterized by two distinct beat rates, the faster of which is four times the slower. Submarines (E) and (G) are characterized by similar dual beat rates. Because the perception of dual beat rates has operational significance for target classification, we are inclined to think that ψ_5 is a meaningful perceptual dimension, which we have tentatively labelled DUAL BEATS. This dimension did not appear in Experiment 1.

The SINDSCAL 18 Analyses

It will be recalled that SINDSCAL 18 involved similarity judgments of the same 14 recorded sonar signals that appeared in SINDSCAL 14, but, in addition, judgments of the similarity of each stimulus to the Sonar Technicians' stereotypical concept of the four basic operational target classes: Submarine, Warship, Light Craft, and Cargo Ship. The complete pairwise matrix also required estimates of the degree of similarity between target class stereotypes. As noted earlier, these were not obtained from the observers directly but, to satisfy the requirements of the SINDSCAL program, it was necessary to provide arbitrary, though defensible, estimates of similarity in lieu of these judgments. It seemed likely that the impact of either set of estimates[4] on the SINDSCAL solution would be minor, since only 6 out of 153 pairs of similarity judgments were affected.

Two SINDSCAL 18 analyses were run, one reflecting each of the two estimates of the similarity between conceptual stereotypes. It will be seen that our assumption that the impact of differences imposed by these two sets of estimated values would be negligible was not supported by the results. There were notable differences as reflected in Table 7 for the two SINDSCAL-18 4-dimensional solutions and in Table 8 for the two SINDSCAL 18 5-dimensional solutions. Since all other data in the similarities matrix were identical except for the six values reflecting the degree of estimated similarity among target class stereotypes, it must be concluded that the SINDSCAL analyses were quite sensitive to relatively minor scale-differences in similarity judgments. This is perhaps likely when the stimuli are complex and have substantial projections on two or more dimensions as was the case

[4]It will be recalled that, under Assumption A, all distances between the conceptual stereotypes were treated as equal (Scale Value = 5), whereas, under Assumption B, they varied from 2 to 7, based on the judgments of one highly experienced Sonar Technician.

Table 7

SINDSCAL 18

Four Dimensional Solution Using Two Different Estimates (A or B)

of Differences Among Conceptual Stereotypes

$\psi_1(A)$		$\psi_1(B)$		$\psi_2(A)$		$\psi_2(B)$	
SUBMARINE (O)	422	LIGHT CRAFT (R)	403	LIGHT CRAFT (R)	451	CARGO SHIP (P)	375
Submarine (E)	335	Sheet Cav. (C)	346	Flutter (B)	355	SUBMARINE (O)	299
Sheet Cav. (C)	281	Submarine (E)	329	Cargo Ship (L)	311	Cargo Ship (K)	262
LIGHT CRAFT (R)	213	Warship (I)	255	Submarine (E)	175	Comp. Cav. (D)	194
Submarine (G)	205	SUBMARINE (O)	239	Cargo Ship (A)	169	Submarine (F)	167
Warship (I)	185	Flutter (B)	118	WARSHIP (Q)	144	Submarine (G)	131
Comp. Cav. (D)	069	Submarine (G)	043	CARGO SHIP (P)	110	Warship (J)	114
Light Craft (M)	063	Light Craft (M)	010	SUBMARINE (O)	090	Light Craft (M)	073
Submarine (F)	041	Cargo Ship (L)	007	Submarine (G)	000	Sheet Cav. (C)	066
						Light Craft (N)	012
						Submarine (R)	015
						Warship (I)	010
Warship (J)	-019	Comp. Cav. (D)	-063	Cargo Ship (K)	-004		
Flutter (B)	-084	Warship (J)	-067	Sheet Cav. (C)	-005		
WARSHIP (Q)	-119	Submarine (F)	-070	Warship (H)	-079		
Light Craft (N)	-143	WARSHIP (Q)	-118	Light Craft (N)	-239	LIGHT CRAFT	-038
CARGO SHIP (P)	-182	Light Craft (N)	-168	Warship (I)	-244	WARSHIP (Q)	-263
Cargo Ship (K)	-200	Warship (H)	-227	Comp. Cav. (D)	-265	Cargo Ship (A)	-287
Cargo Ship (L)	-311	Cargo Ship (A)	-293	Light Craft (M)	-272	Warship (H)	-319
Cargo Ship (A)	-368	CARGO SHIP (P)	-316	Warship (J)	-283	Flutter (B)	-332
Warship (H)	-388	Cargo Ship (K)	-424	Submarine (F)	-349	Cargo Ship (L)	-480
Variance Accounted for	12.3%	Variance Accounted for	12.1%	Variance Accounted for	10.6%	Variance Accounted for	10.1%

Table 7 (Continued)

SINDSCAL 18

Four Dimensional Solution Using Two Different Estimates (A or B)

of Differences Among Conceptual Stereotypes

ψ_3(A)		ψ_3(B)		ψ_4(A)		ψ_4(B)	
Cargo Ship (L)	348	Submarine (F)	306	LIGHT CRAFT (R)	393	LIGHT CRAFT (R)	290
Warship (I)	275	Light Craft (M)	283	WARSHIP (Q)	294	Warship (I)	250
Flutter (B)	236	Warship (I)	277	CARGO SHIP (P)	203	Warship (J)	246
Sheet Cav. (C)	218	Warship (J)	204	Warship (I)	186	Light Craft (M)	179
Warship (H)	216	Comp. Cav. (D)	195	Warship (J)	172	Sheet Cav. (C)	166
LIGHT CRAFT (R)	174	WARSHIP (Q)	191	Light Craft (M)	165	Light Craft (N)	160
Submarine (E)	103	Light Craft (N)	173	Sheet Cav. (C)	149	CARGO SHIP (P)	100
Light Craft (M)	043	Sheet Cav. (C)	099	Light Craft (N)	107	WARSHIP (Q)	088
		Submarine (G)	093	Cargo Ship (K)	052	Cargo Ship (K)	088
Light Craft (N)	-005	Warship (H)	047	Submarine (F)	021	Cargo Ship (L)	066
Warship (J)	-015					Submarine (F)	053
Cargo Ship (A)	-030	Submarine (E)	-056	Cargo Ship (L)	-025	Warship (H)	004
Submarine (F)	-040	SUBMARINE (O)	-060	Flutter (B)	-136		
WARSHIP (Q)	-076	Cargo Ship (A)	-132	Warship (H)	-142	Flutter (B)	-110
Comp. Cav. (D)	-111	Cargo Ship (K)	-220	Cargo Ship (A)	-147	Comp. Cav. (D)	-119
SUBMARINE (O)	-126	Cargo Ship (L)	-274	SUBMARINE (O)	-151	Cargo Ship (A)	-137
Submarine (G)	-161	Flutter (B)	-284	Comp. Cav. (D)	-107	SUBMARINE (O)	-281
CARGO SHIP (P)	-514	CARGO SHIP (P)	-399	Submarine (E)	-440	Submarine (E)	-464
Cargo Ship (K)	-534	LIGHT CRAFT (R)	-442	Submarine (G)	-534	Submarine (G)	-580
Variance Accounted for	10.6%	Variance Accounted for	10.1%	Variance Accounted for	9.9%	Variance Accounted for	9.8%

Total Variance Accounted for: Estimate A - 46.8%; Estimate B - 45.7%

Table 8

SINDSCAL 18

Five Dimensional Solution Using Two Different Estimates

of Differences Among Conceptual Stereotypes

Ψ_1(A)		Ψ_1(B)		Ψ_2(A)		Ψ_2(B)	
Sheet Cav. (C)	378	SUBMARINE (O)	277	LIGHT CRAFT (R)	509	SUBMARINE (O)	346
Warship (I)	370	Submarine (E)	271	Flutter (B)	333	Submarine (F)	337
Submarine (E)	304	LIGHT CRAFT (R)	267	Submarine (E)	287	CARGO SHIP (P)	315
Warship (J)	192	Sheet Cav. (C)	237	Cargo Ship (L)	277	Light Craft (M)	204
SUBMARINE (O)	168	Submarine (G)	161	Sheet Cav. (C)	089	Comp. Cav. (D)	177
Comp. Cav. (D)	154	Warship (I)	159	Cargo Ship (K)	087	Submarine (G)	146
Light Craft (M)	095	Flutter (B)	139	SUBMARINE (O)	061	Light Craft (N)	114
LIGHT CRAFT (R)	075	Cargo Ship (L)	080	WARSHIP (Q)	026	Sheet Cav. (C)	065
Submarine (F)	051	Light Craft (M)	032	Cargo Ship (A)	024	Warship (I)	046
Submarine (G)	023	Submarine (F)	010	Cargo Ship (P)	011	Warship (J)	034
		WARSHIP (Q)	010				
Light Craft (N)	-061			Submarine (G)	-071	Cargo Ship (K)	-054
Cargo Ship (K)	-095	Comp. Cav. (D)	-090	Warship (I)	-111	LIGHT CRAFT (R)	-115
Flutter (B)	-128	Warship (H)	-094	Warship (H)	-154	Submarine (E)	-134
Warship (H)	-242	Cargo Ship (A)	-102	Warship (J)	-159	WARSHIP (Q)	-151
Cargo Ship (L)	-253	Light Craft (N)	-125	Comp. Cav. (D)	-222	Cargo Ship (A)	-206
WARSHIP (Q)	-262	Warship (J)	-227	Light Craft (M)	-297	Warship (H)	-242
CARGO SHIP (P)	-344	CARGO SHIP (P)	-353	Light Craft (N)	-297	Flutter (B)	-403
Cargo Ship (A)	-427	Cargo Ship (K)	-652	Submarine (F)	-410	Cargo Ship (L)	-482
Variance Accounted for	12.9%	Variance Accounted for	12.7%	Variance Accounted for	11.0%	Variance Accounted for	11.6%

Table 8 (Continued)

SINDSCAL 18

Five Dimensional Solution Using Two Different Estimates

of Differences Among Conceptual Stereotypes

ψ_3(A)		ψ_3(B)		ψ_4(A)		ψ_4(B)	
LIGHT CRAFT (R)	402	LIGHT CRAFT (R)	360	SUBMARINE (O)	369	Warship (J)	362
WARSHIP (Q)	306	Warship (I)	271	Submarine (G)	272	Warship (I)	360
Light Craft (M)	148	Sheet Cav. (C)	197	LIGHT CRAFT (R)	175	Sheet Cav. (C)	208
Warship (I)	194	Light Craft (M)	197	Submarine (E)	160	Comp. Cav. (D)	208
CARGO SHIP (P)	162	Warship (J)	163	Flutter (B)	134	Submarine (E)	166
Sheet Cav. (C)	147	Light Craft (N)	149	WARSHIP (Q)	101	Light Craft (M)	159
Light Craft (N)	123	WARSHIP (Q)	122	Submarine (F)	101	WARSHIP (Q)	104
Warship (J)	109	Cargo Ship (L)	120	Sheet Cav. (C)	050	Submarine (F)	100
Submarine (F)	068	Submarine (F)	068	Light Craft (M)	074	Cargo Ship (K)	051
		CARGO SHIP (P)	038	Cargo Ship (L)	046	Light Craft (N)	042
Cargo Ship (L)	-004	Warship (H)	011	Cargo Ship (A)	014	Submarine (G)	012
SUBMARINE (O)	-107			Warship (I)	011		
Cargo Ship (A)	-111	Flutter (B)	-060			Warship (H)	-058
Warship (H)	-116	Cargo Ship (A)	-107	Warship (H)	-043	SUBMARINE (O)	-152
Cargo Ship (K)	-118	Cargo Ship (K)	-109	Light Craft (N)	-068	Flutter (B)	-186
Flutter (B)	-127	Comp. Cav. (D)	-169	Comp. Cav. (D)	-120	Cargo Ship (L)	-248
Comp. Cav. (D)	-194	SUBMARINE (O)	-229	CARGO SHIP (P)	-250	LIGHT CRAFT (R)	-302
Submarine (E)	-456	Submarine (E)	-453	Warship (J)	-321	Cargo Ship (A)	-310
Submarine (G)	-506	Submarine (G)	-568	Cargo Ship (K)	-706	CARGO SHIP (P)	-515
Variance Accounted for	9.8%	Variance Accounted for	9.6%	Variance Accounted for	9.3%	Variance Accounted for	8.5%

Table 8 (Continued)

SINDSCAL 18

Five Dimensional Solution Using Two Different Estimates of Differences Among Conceptual Stereotypes

ψ_5(A)		ψ_5(B)	
CARGO SHIP (P)	421	LIGHT CRAFT (R)	452
SUBMARINE (O)	398	SUBMARINE (E)	335
Submarine (G)	272	Cargo Ship (K)	274
Cargo Ship (K)	248	Sheet Cav. (C)	201
WARSHIP (Q)	100	SUBMARINE (O)	152
Submarine (F)	089	CARGO SHIP (P)	134
Comp. Cav. (D)	074	Flutter (B)	110
Submarine (E)	022	Warship (J)	087
Light Craft (M)	010	Warship (I)	069
LIGHT CRAFT (R)	-003	Comp. Cav. (D)	-021
Light Craft (N)	-060	Submarine (G)	-038
Warship (J)	-061	Cargo Ship (L)	-091
Sheet Cav. (C)	-080	Light Craft (M)	-712
Cargo Ship (A)	-101	Light Craft (N)	-219
Warship (I)	-199	Submarine (F)	-241
Flutter (B)	-271	Cargo Ship (A)	-336
Warship (H)	-402	Warship (H)	-344
Cargo Ship (L)	-453	WARSHIP (Q)	-353
Variance Accounted for	8.9%	Variance Accounted for	8.0%

Total Variance Accounted for: Estimate A - 51.9%; Estimate B - 50.4%

with many of the stimuli in this study.

To conveniently compare the similarity of results under the two assumptions, product-moment correlations were computed between projections of the stimuli on each dimension under Assumptions A and B for both the 4- and 5-dimensional solutions of SINDSCAL 18. The results are shown in Tables 9 and 10. It is evident that some dimensions were clearly the same (e.g., in the 4-D solution, $\psi_{1A} = \psi_{1B}$ and $\psi_{4A} = \psi_{4B}$), while in other cases there were considerable differences (e.g., in the 4-D solution ψ_{3A} most closely resembles ψ_{2B}, but it also bears a substantial similarity to ψ_{1B}).

Confronted with these results, we decided once again to let the criterion of relative interpretability guide us in the selection of the "better" of the two SINDSCAL 18 solutions. Usually, but not always, Assumption B, i.e., the assumption of differential distances between conceptual stereotypes, led to the more interpretable results.

Interpretation of SINDSCAL 18--Four Dimensional Solution

The projections of the 18 stimuli on four perceptual dimensions are compared for the two SINDSCAL 18 solutions in Table 7. The apparent nature of each of these dimensions will be discussed as well as the relative "goodness" of the solutions obtained under the two assumptions. In that table, the projection of a target class stereotype on a given dimension can be differentiated from recorded target signals by the appearance of the name of each stereotype in capital letters.

Table 9

SINDSCAL 18

Correlations Among Four Dimensions Using Two Different Estimates of Distances Among Conceptual Stereotypes

		Estimate B			
		ψ_{1B}	ψ_{2B}	ψ_{3B}	ψ_{4B}
Estimate A	ψ_{1A}	.81*	.51*	.21	-.27
	ψ_{2A}	.24	-.45	-.85	-.21
	ψ_{3A}	.61*	.69*	.14	-.15
	ψ_{4A}	.03	.04	-.03	.93

A correlation of .47 is significant from zero at the .05 level; .59 is significant from zero at the .01 level.

*The differences between .81 and .61 in the first column and between .69 and .51 in the second column are not statistically significant. Thus, it must be cautioned that the order-of-resemblance observed between two such dimensions might not be reliable.

Table 10

SINDSCAL 18

Correlations Among Five Dimensions Using Two Different Estimates of Distance Among Conceptual Stereotypes

		Estimate B				
		ψ_{1B}	ψ_{2B}	ψ_{3B}	ψ_{4B}	ψ_{5B}
Estimate A	ψ_{1A}	.46	.36	.00	.73	.52
	ψ_{2A}	.32	-.60	.00	-.47	.62
	ψ_{3A}	.00	-.08	.93	.00	.00
	ψ_{4A}	.92	.09	-.20	-.13	-.10
	ψ_{5A}	-.20	.75	-.38	-.12	-.28

A correlation of .47 is significant from zero at the .05 level; .59 is significant from zero at the .01 level.

Beat Tonality. The two solutions (ψ_{1A} and ψ_{1B}) are in substantial agreement (r = .81) concerning the stimuli that project strongly on this dimension. ψ_{1B} is somewhat easier to interpret. Cargo Ship (K), Cargo Ship (A), and Warship (H) are all characterized by clearly perceptible strong beats, but Cargo Ship (K) has very tonal beats as does Warship (H). The appearance of the CARGO SHIP stereotype is significant in this context, because clear tonal beats are viewed as characteristic of the cargo ship class. Thus, this dimension seems to be BEAT TONALITY which we also identified in SINDSCAL 14. ψ_2 in SINDSCAL 14 and ψ_{1B} in SINDSCAL 18 correlated .76. It is notable that Cargo Ship (K), which had the highest projection on this dimension, was rated close to the CARGO SHIP stereotype, and that 22 of the 26 Sonar Technicians classified this stimulus as "cargo." Cargo Ship A was similarly judged to be closer to the CARGO SHIP stereotype than any other class, and 15 of the 26 observers correctly classified it as such.

The opposite extreme of this dimension is defined by the LIGHT CRAFT stereotype and such stimuli as Sheet Cavitation (C) which has undiscernible beats and Warship (I) which has very weak beats. Submarine (E) in this company is somewhat more difficult to rationalize since it does have discernible beats, but they are rapid and "squeaky." The appearance of the LIGHT CRAFT stereotype at the opposite extreme of dimension ψ_{1B} very likely reflects the Solution B assumption concerning the fairly strong dissimilarity between cargo ships and light craft that is incorporated into the instructional program on "nature of sound" target classification. It will be noted that these two stereotypes are clearly separated in ψ_{1A}, but they do not play the definitive roles that they do in ψ_{1B}. It is also of interest that one light craft signal in the data set (Light Craft (N)) was judged to resemble the CARGO SHIP stereotype more strongly than its own class stereotype. This item was correctly classified by only 3 of the 26 Sonar Technicians, testifying to its dissimilarity to the LIGHT CRAFT stereotype.

<u>Beat Clarity</u>. One of the two dimensions (ψ_{2A} and ψ_{2B}) is clearly the inverse of the other (r = -.85) in the two solutions, and each is relatively independent of the other dimensions. This dimension was seen in the SINDSCAL 14 solution and is defined by stimuli having rapid, clear beats. We have seen Flutter (B) and Cargo Ship (L) together before. The nature of the dimension is further identified by the appearance of LIGHT CRAFT and CARGO SHIP stereotypes on ψ_{2B}. In contrast to their position on first dimension, these stereotypes now appear together, and the reason for this is suggested by the nature of the other stimuli having high projections on this dimension. The factor in common is the appearance of pronounced rapid beats and these can be generated by either the shaft rate of light craft operating at a high RPM or the blade rate of cargo ships which can approximate the shaft rate of light craft. This indeed was a characteristic of Cargo Ship (L) which was judged to resemble the LIGHT CRAFT stereotype more closely than it did its own class.

The stimuli at the opposite extreme of this dimension, Submarine (F), Light Craft (M), Warship (I), and Warship (J) all are characterized by extremely weak beats of moderate rate. These same stimuli tend to appear at the opposite extreme in both solutions, and, since they are of a diverse nature otherwise, what they seem to have in common is the virtual absence of the rapid pronounced beat pattern so characteristic of Flutter (B). Thus, this dimension appears to be BEAT CLARITY, which we also saw in SINDSCAL 14. ψ_{3B} in SINDSCAL 18 correlated .93 with ψ_1 in SINDSCAL 14.

It is of interest that ψ_{2A} and ψ_{3B} probably come closest in character to the dimension identified by Howard as "low frequency periodicity." Flutter (B) had a projection on this dimension in Howard's study, as did Biologics, a stimulus that was not included in SINDSCAL 18. There seems little doubt that had it been, it would have emerged on one of the beat factors identified in the present analysis, possibly on ψ_{2A} and ψ_{3B}. It is important to note, however, that low frequency periodicity is a characteristic of several of the perceptual dimensions identified in SINDSCAL 14 and SINDSCAL 18, and one must seek further elaboration of periodicity as a dimension of sonar sounds if the nature of the classification response is to be fully understood. For example, Biologics is the only stimulus in either study that is characterized by a pattern of temporally irregular beats. Thus, had it been included in the present study, it might have emerged on yet another dimension. Certainly, Sonar Technicians (generally speaking) have little difficulty recognizing biological signals, in part because of their irregular beat pattern. Twenty-four of the 26 Sonar Technicians in the present study classified the Biologics example correctly.

Beat Rate. The moderate correlation ($r = .69$) of these two sets of stimulus projections (ψ_{3A} and ψ_{2B}) testifies to the lack of clear definition of the underlying dimension. It is evident from the table of correlations (Table 9) that the stimuli project substantially on other dimensions as well. Nevertheless, there are distinguishing characteristics of ψ_{3A} and ψ_{2B} which are at least suggestive of the underlying perceptions.

A striking characteristic, seen in both Assumption A and Assumption B solutions, is the strong involvement of the conceptual stereotype CARGO SHIP and Cargo Ship (K) at one extreme and Cargo Ship (L) and Flutter (B) at the other. This result is not as contradictory as it might at first seem.

Cargo Ship (K) has the slowest beat in the entire stimulus set, and slow pronounced beats are associated with the CARGO SHIP stereotype in classification training. It is of interest that 22 of the 26 Sonar Technicians correctly classified Cargo Ship (K) as cargo.

Cargo Ship (L), which is at the opposite extreme of this dimension, is characterized by dual rapid and moderate beats that have a static quality. This stimulus is closely associated with Flutter (B), and the rapid atonal character of these beats is probably responsible for the fact that most Sonar Technicians rated Cargo Ship (L) close to the LIGHT CRAFT stereotype.

Considering the overall pattern of results, this dimension is considered to be BEAT RATE, a dimension also seen in SINDSCAL 14 (ψ_4). However, in this case, the correlation between the two sets of stimulus projections in the two solutions was only .51.

Squeaky Beats (vs. HISS). The high correlation (r = .93) between the projections of stimuli on this dimension in the two solutions (ψ_{4A} and ψ_{4B}) and the lack of significant correlation with any other dimension does much to insure that this perceptual dimension is well defined.

ψ_{4A} and ψ_{4B} are characterized by the strong projections of Submarine (G) and Submarine (E) in both solutions and, at the opposite extreme, by the LIGHT CRAFT stereotype and various warship stimuli. The submarine signals, which do much to define this dimension, have a unique characteristic that we earlier called "SQUEAKY BEATS." It will be noted that the SUBMARINE stereotype also projects on this dimension. Evidently, the perception of "squeaky beats," perhaps along with other discernible characteristics, permitted the Sonar Technicians in this study to enjoy a high degree of success in classifying these two stimuli; 25 of the 26 technicians correctly classified both as submarine targets.

There is nothing in the original set of 8 stimuli employed by Howard that would permit the identification of this perceptual dimension. Howard's ψ_1, which he describes as "homogeneous vs. more than one sound" was not viewed as having periodicity, a feature that is clearly involved in the present case, even though more than one sound is obviously present in Submarine (E) and Submarine (G).

The nature of the stimuli at the opposite ends of ψ_{4A} and ψ_{4B} is worthy of note. Though several conceptual stereotypes appear, suggesting that "squeaky beats" are rarely if ever associated with other than submarines, the two sonar stimuli that were closest to the opposite extreme were Warships (I) and (J). Insofar as this analysis is concerned, this is of potential significance since we identified no other dimension that appears to separate warships from other target classes. Warship (I) and Warship (J) are both characterized by a dominant broadband hissing quality and very weak moderate rate beats. The beat rate is not greatly different from that produced by the submarines, so we are inclined to believe that the significant perceptual element is the broadband hiss. This is not the exclusive property of warships and indeed the LIGHT CRAFT stereotype appears in company with these stimuli. It is, however, a characteristic that receives some emphasis in the training of Sonar Technicians for recognizing warships. The technicians had considerable trouble in classifying these stimuli, and, in fact, Warship (I) was viewed as falling closer to the LIGHT CRAFT stereotype than any other target class. Only 6 of the 26 Sonar Technicians correctly classified this target, the predominant response being "light craft." They did somewhat better with Warship (J) which was judged to resemble the WARSHIP stereotype much more closely; 11 of the 26 classifications of this stimulus were correct. Difficulty in the classification of surface warships has been noted in earlier research on target classification (Mackie, et al., 1968). In all likelihood, it reflects the absence of a definitive characteristic in the signals produced by warships which may be relied upon as a more or less unique indicator of the class.

It may be recalled that "HISS" also appeared in Experiment 1 at the opposite extreme of a dimension that we called TONALITY. Indeed, HISS appears to be the logical opposite of TONALITY. It may have emerged as the opposite of SQUEAKY BEATS in SINDSCAL 18 because there were no stimuli which had a more continuous tonal character.

Interpretation of SINDSCAL 18--Five-Dimensional Solution

As mentioned earlier, a 5-dimensional solution for SINDSCAL 18 was considered defensible in view of the variance-accounted-for/degrees-of-freedom ratio. Thus, it was decided to examine the interpretability of the 5-dimensional solution in the interest of accounting for a greater proportion of the variance in the similarity judgments. Again, solutions were compared using Estimate "A" and Estimate "B" regarding the distances between conceptual stereotypes.

The intercorrelation matrix of the five perceptual dimensions emerging from this analysis is shown in Table 10. Again, it will be observed that the two assumptions produced some strong similarities in the emerging dimensions but, in some instances, considerable overlap with more than one dimension.

Hiss (?). These dimensions (ψ_{1A} and ψ_{4B}) are defined by strong projections by Warship (J), Warship (I), and Sheet Cavitation (C). They appear similar to the broadband HISS factor tentatively identified as the opposite of SQUEAKY BEATS in the four-dimensional solution. This interpretation is supported by the presence of Sheet Cavitation (C) which is characterized by broadband hiss and weak or no discernible beats. Sheet Cavitation also played a prominent role in defining HISS in Experiment 1. Warships I and J also have very weak extreme of this dimension shows strong projection by the CARGO SHIP stereotype and Cargo Ship (A) which involved pronounced dual beats. This may be a remnant of the DUAL BEAT dimension which emerged as a fifth dimension in SINDSCAL-14.

Beat Clarity. ψ_{2A} in this analysis correlates about equally with both ψ_{2B} and ψ_{5B} ($r = .62$), making its nature somewhat obscure. It involves the clear, rapid beats, associated both with Flutter (B) and the LIGHT CRAFT stereotype. Flutter appears with Cargo Ship (L), which, it will be remembered, has rapid, static-like beats that were also associated with the LIGHT CRAFT stereotype.

However, ψ_{5B} clearly is not the rapid beat factor. It is difficult to discern a meaningful rationale for the clustering of stimuli at either end of this dimension. No stimuli appear to strongly resemble any other, or the classification stereotypes with which they are seen, in any obvious way. It is concluded that the principal perceptual dimension involved here is BEAT CLARITY, although the definition is poorly defined compared to the 4-dimensional results.

Squeaky Beats. These dimensions (ψ_{3A} and ψ_{3B}) are clearly like the "SQUEAKY BEAT" dimension identified in the 4-dimensional analysis. Once again, it is dominated by Submarine (E) and Submarine (G), with the LIGHT CRAFT stereotype defining the opposite extreme of the dimension. The two solutions (ψ_{3A} and ψ_{3B}) correlated .93.

Beat Tonality. These dimensions (ψ_{4A} and ψ_{1B}) show the very strong projection of Cargo Ship (K) which we previously associated with BEAT TONALITY in SINDSCAL-14. The two solutions (ψ_{4A} and ψ_{1B})

are in strong agreement ($r = .92$), and there is a substantial association with the CARGO SHIP stereotype.

Beat Rate. These dimensions (ψ_{5A} and ψ_{5B}) appear to be like the flutter or RAPID BEAT dimension previously discussed. Both solutions (ψ_{5A} and ψ_{5B}) show strong projections by Cargo Ship (L), which was characterized by a static-like, rapid beat, Flutter (B), and Warship H which had a very rapid beat rate. The correlation between solutions was .75. SUBMARINE and CARGO SHIP stereotypes occupy the opposite extreme of this dimension, and, since very rapid beats are rarely associated with these classes, their position in the stimulus space is generally supportive of the interpretation given to this dimension.

Comparison of Dimensions Between SINDSCAL 14 and SINDSCAL 18

It was felt that there was insufficient clarity in the 5-dimensional SINDSCAL 18 solution to justify an attempt to define more than four perceptual dimensions. A similar conclusion was reached, it will be recalled, with respect to SINDSCAL 14. Thus, a remaining question of interest concerned the similarity of dimensions in the SINDSCAL 14 and SINDSCAL 18 4-dimensional solutions. It would be expected, of course, that the presence of conceptual stereotypes in SINDSCAL 18 might considerably change the structure of the underlying stimulus space since, as we have seen the arrangement of that space was quite sensitive to small but systematic shifts in similarity judgments. Pearson correlation coefficients were computed to answer this question with the results shown in Table 11. It will be seen that

Table 11

Correlation of Dimensions from SINDSCAL 14

and SINDSCAL 18 Four-Dimensional Solutions

		SINDSCAL 18 (Estimate B)			
		ψ1B	ψ2B	ψ3B	ψ4B
SINDSCAL 14	ψ1	.20	.78	.93	.34
	ψ2	-.76	.16	-.07	.60
	ψ3	.00	-.47	.19	.70
	ψ4	-.17	-.51	-.07	-.17

A correlation of .53 is significant from zero at the .05 level; .66 is significant from zero at the .01 level.

three of the four pairs of dimensions correlated very significantly ($P < .01$) with each other but that the remaining pair just missed significance at the .05 level.

The first pair, ψ_1 and ψ_{3B} ($r = .93$), defines the BEAT CLARITY dimension. Cargo Ship (L), Cargo Ship (A), and Flutter (B) dominate the SINDSCAL 14 solution; Flutter (B), Cargo Ship (L), Warship (H), and Cargo Ship (A) project strongly in the SINDSCAL 18 solution. Warship (H) was characterized by a pronounced periodic "thump" which supports the interpretation. At the opposite extreme are two stimuli, Submarine (F) and Light Craft (M) which had extremely weak and variable beats.

ψ_2 in SINDSCAL 14 and ψ_{1B} in SINDSCAL 18 are dimensions that are inversely related ($r = -.76$). The comparison is complicated, because ψ_2 in SINDSCAL 14 is characterized by BEAT TONALITY at one end and SQUEAKY BEATS at the other. In SINDSCAL 18, BEAT TONALITY emerges as ψ_{1B}, but SQUEAKY BEATS appear as a different dimension. In any case, BEAT TONALITY is clearly a perceptual characteristic of both analyses.

ψ_3 in SINDSCAL 14 and ψ_{4B} in SINDSCAL 18 clearly are dimensions that suggest a SQUEAKY BEAT dimension ($r = .70$). The opposite pole is better described in the SINDSCAL 18 analysis which is characterized by stimuli having very weak or unpulsed broadband HISS.

ψ_4 dimension in SINDSCAL 14 correlates strongest with the ψ_{2B} dimension in SINDSCAL 18, but the correlation ($r = -.51$) fails of significance at the .05 level. This is evidently a BEAT RATE dimension. Flutter (B) plays a dominant role in both solutions, and stimuli with opposite projections (e.g., Cargo Ship (K)) have very slow beat rates.

SUMMARY

A summarization of the perceptual dimensions tentatively identified from Experiments 1 and 2, plus Howard's original study, is presented in Table 12. The stimuli having projections at the opposite extremes of each dimension are listed and the correlations between solutions are shown. We believe that the first five of these dimensions are reasonably well established. The sixth, DUAL BEATS, is more tentative, having been seen only in SINDSCAL 14, although such a dimension clearly has operational significance for target classification.

Table 12

Summary of Perceptual Dimensions

Dimension	Analyses In Which Appeared[1]		Predominant Stimuli
Beat Rate[2]	γ_1 Howard - 8	r = .82	Flutter, Rain vs. Comp. Cav., Biologics
	γ_1 HFR-8		Flutter, Torpedo vs. Biologics, Sheet Cav.
	γ_4 SINDSCAL-14	r = .51	Flutter, Warship vs. Cargo Ship(K), Sheet Cav.
	γ_{2B} SINDSCAL 18		Cargo Ship(L), Flutter vs. Comp. Cav., Cargo Ship(K)
Beat Clarity[3]	γ_2 Howard - 8	r = .85	Biologics, Flutter vs. Steam, Diesel
	γ_3 HFR - 8		Flutter, Biologics vs. Torpedo, Diesel
	γ_1 SINDSCAL-14	r = .93	Cargo Ship(L), Cargo Ship(A) vs. Light Craft(H) Sub(F)
	γ_{3B} SINDSCAL-18		Flutter, Cargo Ship(L) vs. Light Craft(M) Sub(F)
Tonality[4] (vs. Hiss)	γ_3 Howard - 8	r = .88	Diesel, Biologics vs. Comp. Cav., Sheet Cav.
	γ_2 HFR - 8		Biologics, Torpedo vs. Sheet Cav., Steam
Beat Tonality	γ_2 SINDSCAL-14	r = .76	Cargo Ship(K), Warship(J) vs. Submarine(G), Sub(E)
	γ_{1B} SINDSCAL-18		Cargo Ship(H), Cargo Ship(A) vs. Submarine(E), Sheet Cav.
Squeaky Beats (vs. Hiss)	γ_3 SINDSCAL-14	r = .70	Submarine(G), Cargo Ship(K) vs. Warship(H), Sheet Cav.
	γ_{4B} SINDSCAL-18		Submarine(G), Sub(E) vs. Warship(J), Warship(I)
Dual Beats	γ_5 SINDSCAL-14		Submarine(G), Sub(E) vs. Warship(J), Comp. Cav.

[1]The SINDSCAL-14 and -18 dimensions listed here are from the [illegible]-dimensional solutions.

[2]Howard called this dimension: Homogeneous vs. heterogeneous quality.

[3]Howard called this dimension: Low frequency periodicity.

[4]Howard called this dimension: Tinniness.

PHYSICAL ANALYSIS OF THE STIMULI

Method

All of the 19 separate sonar signals employed in the two experiments were subjected to frequency analyses. These analyses were performed in conjunction with an outside laboratory having existing computer programs for sound analysis. The nature of the analyses and the data display formats for presentation of the results will be described.

Each 3-second stimulus was sampled at a rate of 20 KHz, its amplitude was digitized, and the results were stored on disk file. The frequency content of each stimulus was then analyzed employing the following method. A 512-point Fast Fourier Transform (FFT) algorithm was applied to the first 10 milliseconds of the signal. The result was a discrete approximation of the power spectral density between 0 and 10 KHz within a 10-millisecond "window." The "window" was then advanced 5 milliseconds and the FFT performed again. Thus, the frequency spectrum of the signal segment between 5 milliseconds and 15 milliseconds after onset was derived. The analysis proceeded in this manner, moving the 10-millisecond window forward 5 milliseconds at a time, until the entire 3-second stimulus signal had been analyzed. This procedure resulted in approximately 600 frequency spectra for each of the 3-second signals.

After considerable initial examination, the following method was chosen as the most suitable format for presentation of the results of the frequency analysis. First, every third frequency spectrum was selected for display. That is, segments of the original signal between 0 and 10 milliseconds, between 15 and 25 milliseconds, between 30 and 40 milliseconds, etc., were selected. Thus, the number of spectra to be presented was reduced to 200. Second, the spectrum derived from each of the selected 10-millisecond windows was processed by a "peak picker" algorithm, which determined the location and width of local peaks (i.e., local maxima) within the spectrum. Finally, the results were composed in a format which presented the original time domain signal, the RMS amplitude of the signal, and the results of the frequency spectral analysis. This format was drawn on a Tektronix 4012 Direct View Storage Tube, and the resulting image was also produced in hard copy by a Tektronix 4631 unit.

An example of this output format is shown in Figure 8. All of the data in this format are plotted against a horizontal time base of 3 seconds' duration. The top portion of the format represents the original time-domain signal. This part of the presentation is equivalent to the display one would observe on an oscilloscope if the original signal were connected to the vertical deflection amplifier, and the horizontal sweep generator were triggered by the onset of the signal and produced a sweep of 3 seconds' duration.

In the middle of the figure is a horizontal trace which represents the RMS amplitude of the original time-domain signal. In the example displayed in Figure 8, no large or consistent variations of RMS amplitude are noticeable.

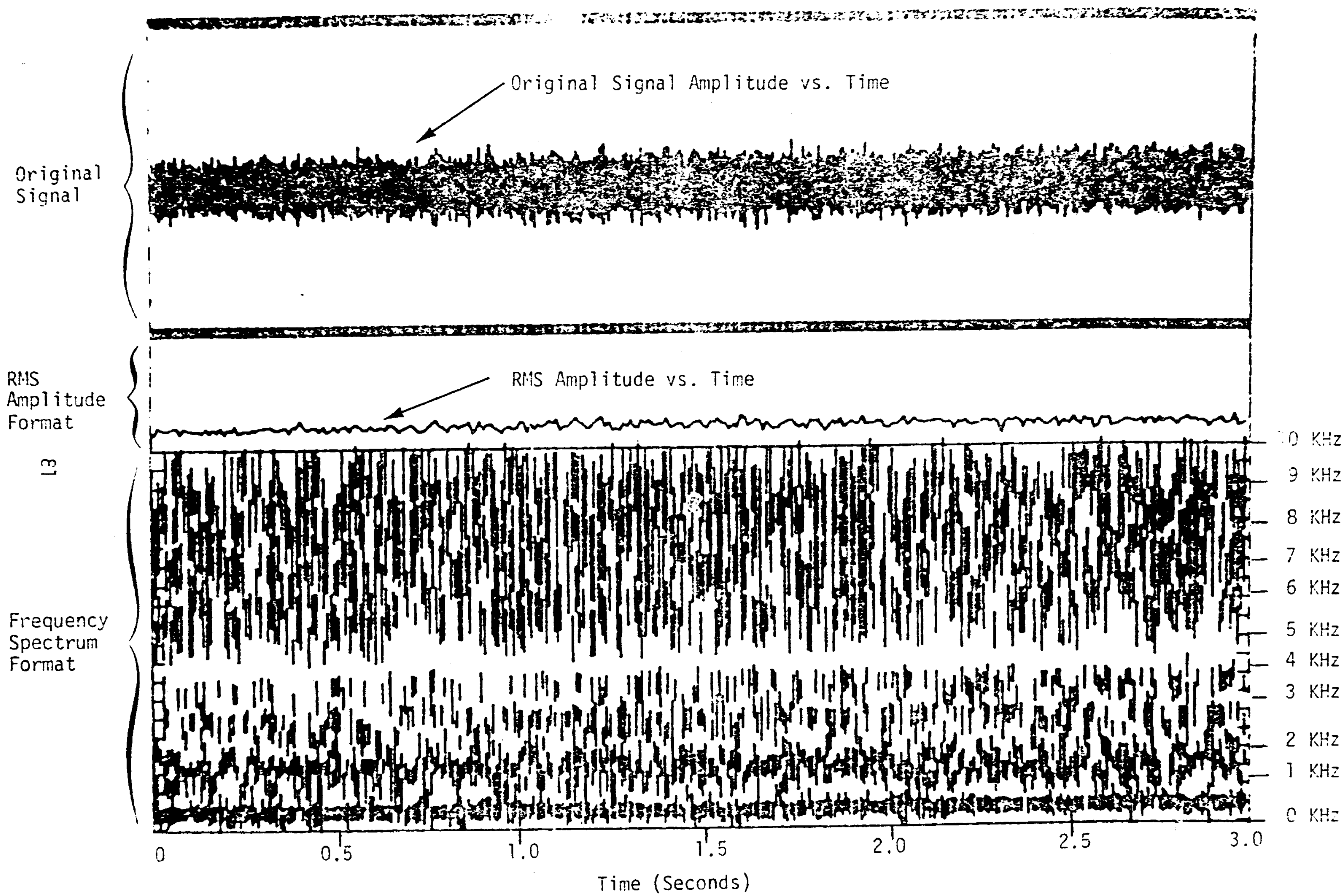


Figure 8. Legends and scales for signal analysis formats.

The bottom portion of the figure illustrates the frequency spectrum format. In this format, 200 frequency spectra are presented, as processed by the "peak picking" algorithm. The frequency spectra are spaced 15 milliseconds apart in the horizontal direction and extend from a frequency of 0 KHz upward to 10 KHz in the vertical direction.

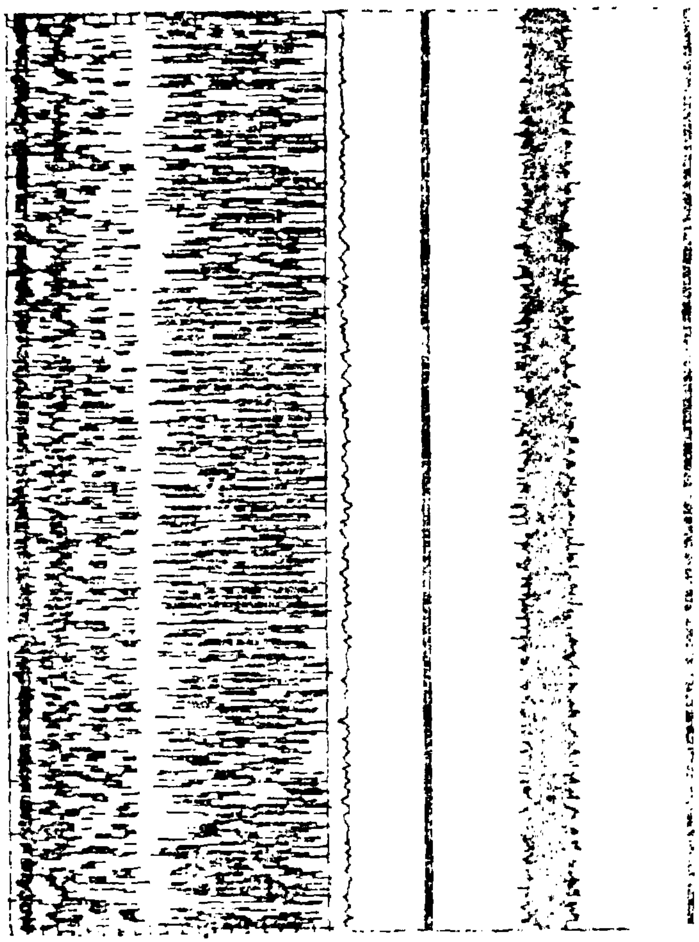
The reader will note that the frequency spectrum format appears to be comprised of a number of vertical lines of varying lengths and locations. These vertical lines are to be interpreted in the following way. Each vertical line represents a local peak in the frequency spectrum of the signal in the ten-millisecond window beginning at the time indicated by the time-scale given on the horizontal axis. The width of the frequency peak is indicated approximately by the vertical extent of the line, and the frequency of the peak is given by its vertical location; each may be interpreted from the frequency scale on the vertical axis.

A number of features in the frequency spectrum format shown in Figure 8 are worthy of note. first, it may be seen that there is a consistently reappearing peak in the frequency spectra throughout the three-second sample (i.e., most of the 200 spectra) at a frequency of approximately 0.4 KHz.

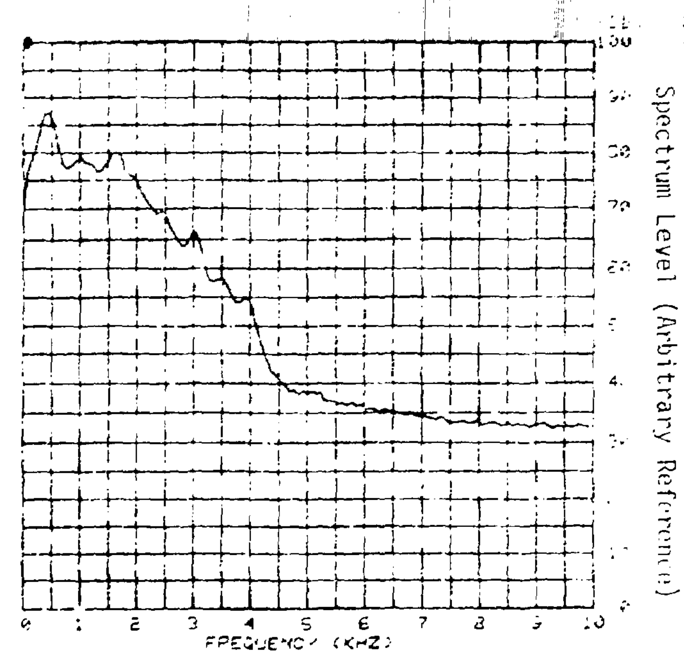
Second, there is a conspicuous absence of peaks in the frequency range of approximately 4.0 KHz to 4.5 KHz. And, finally, the frequency spectra that occur above approximately 5 KHz are notable for their apparently random nature in frequency and range.

Each of these three features may be better understood by reference to an averaged signal spectrum which shows relative spectrum level across the entire analysis bandwidth. In Figure 9A, the signal analysis presentation of Figure 8 is repeated in a smaller format which has been rotated clockwise by 90 degrees. Thus, the earliest time (signal onset) is at the top of the display of "signal properties versus time," and the latest time (3 seconds) is at the bottom. In the frequency spectrum part of the display, frequency is read linearly from 0 Hz at the left to 10 KHz on the right. This orientation is used to present the results of the time-varying properties of the 19 signals because of the ease with which "visual integration" may be performed in order to distinguish better certain infrequent or irregular frequency peaks. In order to employ this technique, the viewer should tilt the page away from himself, so that the figure is viewed along the time axis, and the entire presentation is foreshortened according to the degree of obliquity employed in viewing the page. The presence of certain features in the signal spectrum are more easily detected employing this technique.

Figure 9B presents the averaged power spectral density of the signal (averaged over the entire three seconds) versus frequency. The features which have already been noted regarding the "spectrum versus time" format may be interpreted more fully employing the averaged signal spectrum. First, the recurring peak evident in the spectrum-versus-time display is clearly evident at approximately 0.4 KHz in the averaged signal spectrum. Because this peak recurs so regularly at the same frequency, its intensity builds up in the averaged spectrum, and it is in fact the peak of greatest amplitude in



A. "Signal Properties vs. Time" format



D. "Averaged Signal Spectrum" format

Figure 9. Format of physical analysis presentations.

the spectrum from 0 to 10 KHz, at a (relative) intensity of approximately 86 dB.

The second feature noted earlier regarding the time-varying spectrum was the notable absence of peaks between about 4.0 KHz and 4.5 KHz. It is evident in the averaged signal spectrum that the power spectral density of the signal drops very steeply in this frequency region, without evident peaks, down to what is approximately a "background noise" level. Finally, it was noted that above about 5 KHz, the spectrum-versus-time format showed a randomly-occurring pattern of peaks. It may be seen in the averaged signal spectrum format on the right that the spectrum of this particular signal is <u>very</u> weak in this frequency range (approximately 50 dB, or a power factor of 100,000 down from the peak found at 0.4 KHz). Thus, it can be seen that the peak-picking algorithm does indeed pick <u>local</u> peaks regardless of the existence of far stronger (or weaker) peaks in other "neighborhoods" of the frequency spectrum. The region above 5 KHz is evidently "down in the noise," and, therefore, the peaks occur randomly and are without meaning.

To summarize, the "spectrum versus time" format is valuable for its ability to show <u>variations</u> in the signal spectrum over time, just as the human ear can detect variations in the signal spectrum over the period of time of these signal durations. However, the relative amplitude of peaks in various parts of the signal spectrum is obscured by this format; they are made clear only in the "averaged signal spectrum" format, which serves as an important adjunct for interpreting the sonar signal . The averaged signal spectrum, of course, cannot portray any of the time-varying features of these signals, which may be of considerable importance to human perception; but it does reveal the relative amplitudes of the averaged signal in various parts of the spectrum. Thus, the two methods of presenting frequency analysis data are complementary.

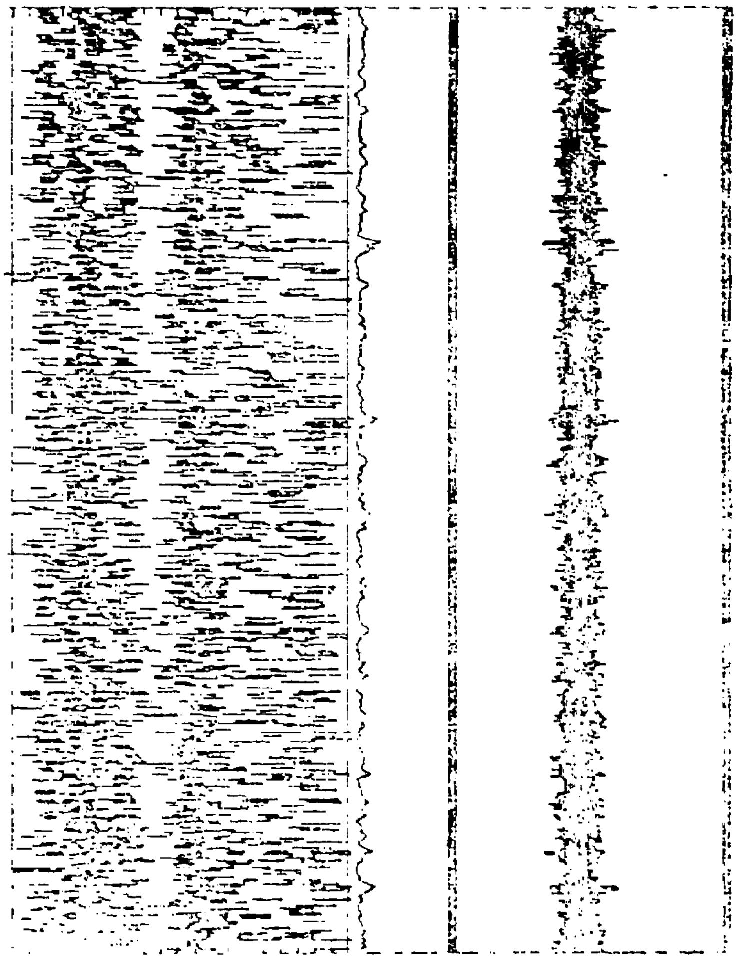
Physical and Psychological Description of the Stimuli

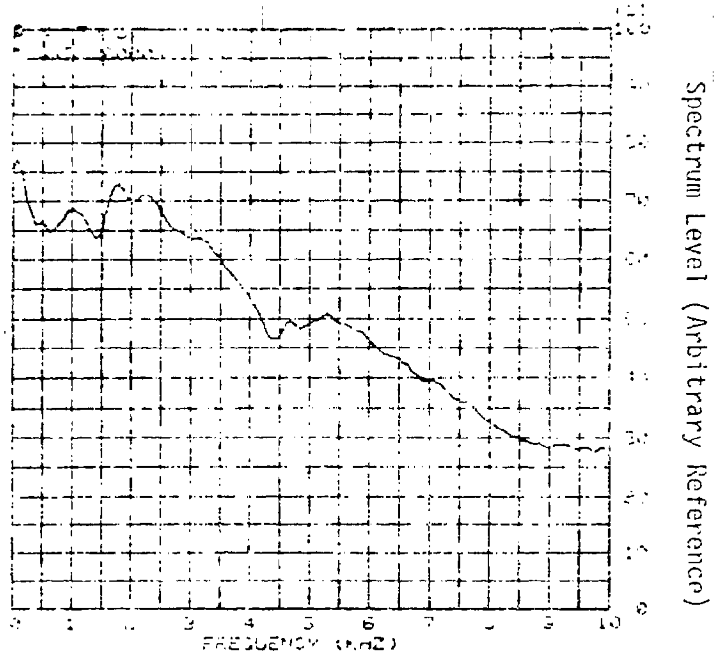
On the pages that follow, each of the 19 stimuli employed in Experiments 1 and 2 is described in terms of the physical analysis performed, certain subjective characteristics judged to be present by the staff, and the projections of each stimulus on the perceptual dimensions identified through the SINDSCAL analyses.

Stimulus 1: Cargo Ship (A)

This target signal (Figure 10) was characterized by two pronounced beat rates, one rapid and the other moderate. It was also characterized by broadband hiss. It had strong projections on two perceptual dimensions: BEAT CLARITY (ψ_{1B}) in SINDSCAL 14 and ψ_{1B} BEAT TONALITY in SINDSCAL 18. In the latter case, it was closely associated with the CARGO SHIP stereotype.

Sonar Technicians had moderate success (58 percent correct) in classifying this target. Examination of the similarity ratings of this signal to the target class stereotypes (Table 3) reveals that the signal was regarded as resembling both CARGO SHIP and WARSHIP stereotypes. Indeed, 38 percent of the Sonar Technicians erroneously classified this signal as "warship."





Two perceptible beat rates: rapid and moderate
Broadband hiss
Closest conceptual stereotype: CARGO SHIP
Classification: 15/26 Cargo Ship
Strong projections:
1 (SINDSCAL 14) BEAT CLARITY
13 (SINDSCAL 18) BEAT TONALITY

Figure 10. Analysis of Stimulus 1: Cargo Ship(A).

Stimulus 2: Flutter (B)

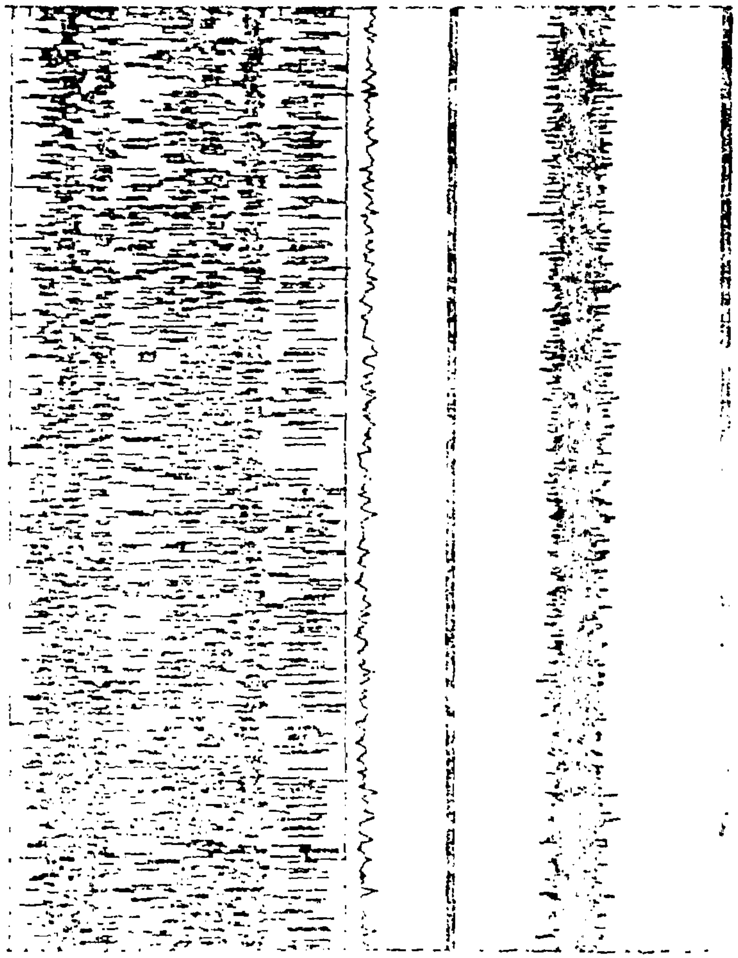
Flutter was characterized in Figure 11 by pronounced rapid beats superimposed on a hissing and roaring background. In addition, it was perceived to have a timbre which can be described as a "metallic" quality. The actual source of this signal is unknown, since it was a member of Howard's original set of eight stimuli. However, Sonar Technicians strongly associated this signal with the LIGHT CRAFT stereotype, and 65 percent classified it as "light craft."

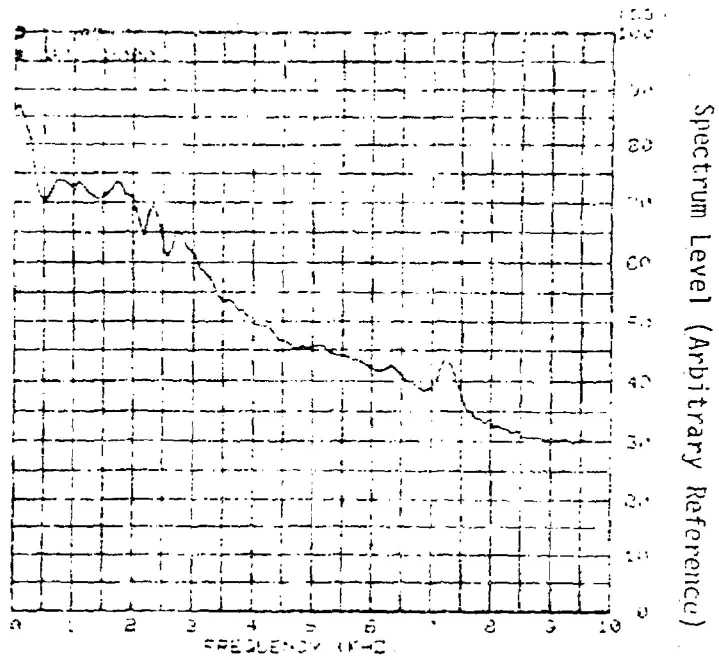
Flutter played a prominent role in two of Howard's three perceptual dimensions and appeared in strong positions as well in both SINDSCAL 14 and SINDSCAL 18. In Howard's analysis, it had a strong projection on ψ_1, "HOMOGENEOUS QUALITY" which, in HFR's replication, we termed BEAT RATE. Flutter also had a high loading on Howard's ψ_2 which he termed LOW FREQUENCY PERIODICITY, and HFR's ψ_3 which we identified as BEAT CLARITY.

Flutter also appeared in both SINDSCAL 14 and SINDSCAL 18 with strong projections on BEAT CLARITY and BEAT RATE. It can be concluded that Flutter was a dominant stimulus in this set and that its perceptual nature was quite complex perceptually. Further, it played an important role in relation to the target classification stereotypes, being associated primarily with Light Craft and to a lesser extent with Warships and Submarines.

Stimulus 3: Sheet Cavitation (SC)

Sheet Cavitation was also a member of Howard's original set of eight stimuli so its actual source is unknown. It is associated, conceptually, with both SUBMARINE and LIGHT CRAFT stereotypes, and





Pronounced rapid beats
Broadband hiss and "roar"
Narrowband: "metallic" sound
Closest conceptual stereotype: LIGHT CRAFT
Classification: 17/26 Light Craft
Strong projections:
Howard .1 HOMOGENEOUS QUALITY
HFR-S .2 BEAT RATE
.1 (SINDSCAL 14) BEAT CLARITY
.3B (SINDSCAL 13) BEAT CLARITY
Howard .2 (LOW FREQ PERIODICITY)
HFR-S .3 BEAT CLARITY
.4 (SINDSCAL 14) BEAT RATE
.2B (SINDSCAL 13) BEAT RATE

Figure 11. Analysis of Stimulus 2: Flutter(S).

nearly equal numbers of Sonar Technicians classified it as a member of one of these classes or the other. Sheet Cavitation (Figure 12) is an unmodulated broadband sound that is characterized more by the absence of clear perceptual characteristics than by any salient features. The beats, if any, in this stimulus are barely perceptible and its background is characterized by broadband hiss.

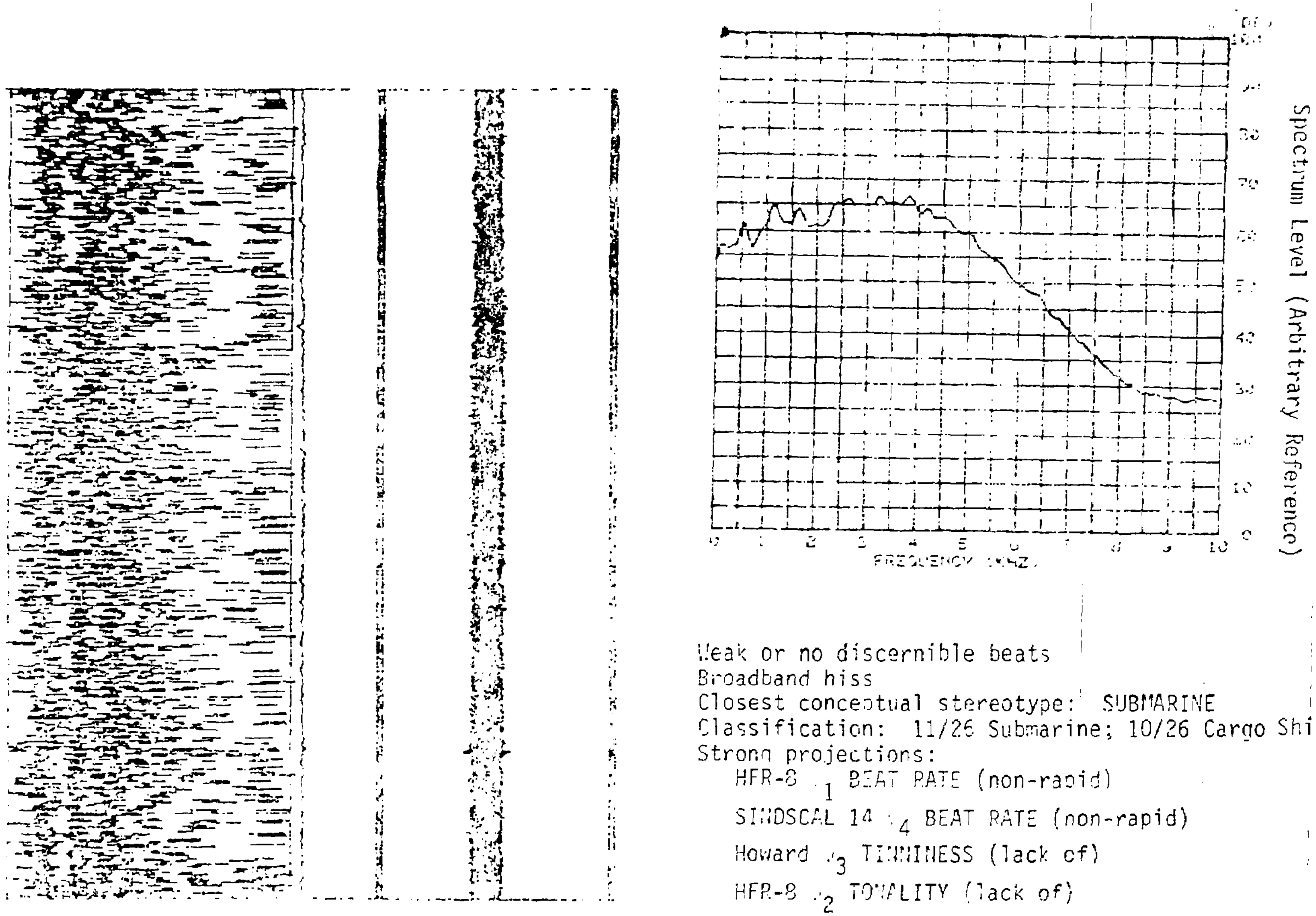
Sheet Cavitation played an important role in one of Howard's perceptual dimension (ψ_2) which he described as (lack of) TINNINESS. It appeared in dominant positions on two of HFR's dimensions in the replication of Howard's study, namely ψ_1 (lack of) RAPID BEATS and ψ_2 (lack of) TONALITY. It also appeared in SINDSCAL 18 on ψ_{1B} (lack of) BEAT TONALITY.

Stimulus 4: Compressed Cavitation (CC)

In contrast to Sheet Cavitation, the Compressed Cavitation signal is characterized by a pronounced slow beat, a background that is both hissing and roaring, and by what is described by observers as a "cranking" sound (Figure 13).

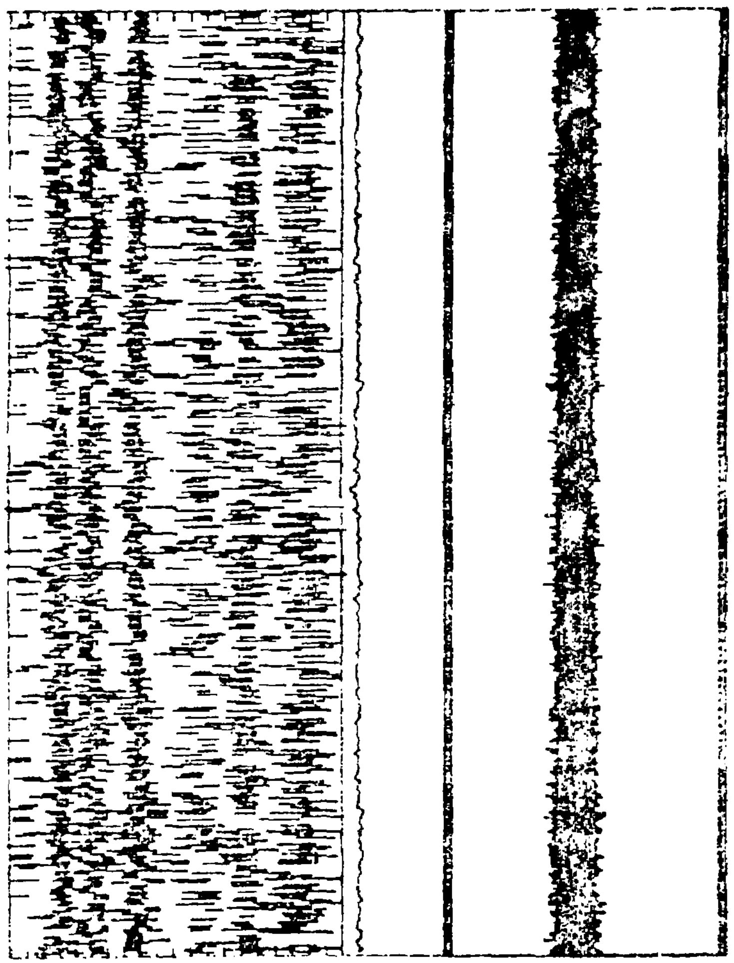
Sonar Technicians associated this type of sound about equally strongly with Submarine and Cargo Ship targets. Indeed, a total of 96 percent classified this signal as having been produced by one or the other of these target classes. Its actual origin is unknown, but it was one of Howard's eight original stimuli.

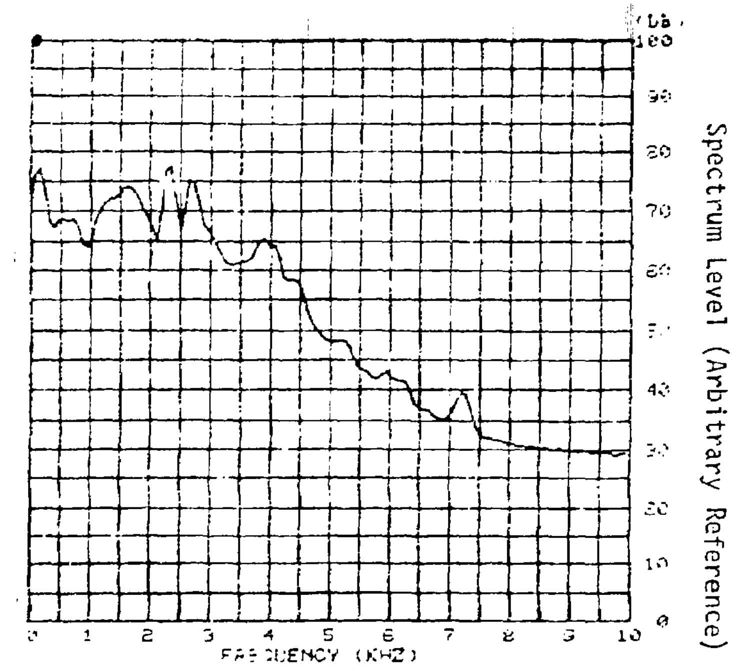
In terms of perceptual dimensions, it had a strong projection on Howard's ψ_1 which he termed HETEROGENEOUS QUALITY and on ψ_{2B} in SINDSCAL 18 which we defined as BEAT RATE. It also had an important



Weak or no discernible beats
Broadband hiss
Closest conceptual stereotype: SUBMARINE
Classification: 11/26 Submarine; 10/26 Cargo Ship
Strong projections:
HFR-8 $_1$ BEAT RATE (non-rapid)
SINDSCAL 14 $_4$ BEAT RATE (non-rapid)
Howard $_3$ TINNINESS (lack of)
HFR-8 $_2$ TONALITY (lack of)
SINDSCAL 13 $_{13}$ BEAT TONALITY (lack of)

Figure 12. Analysis of Stimulus 3: Sheet Cavitation.





Pronounced slow beats
Broadband hiss, roar
"Cranking" sound
Closest conceptual stereotype: SUBMARINE; CARGO SHIP
Classification: 15/26 Submarine; 10/26 Cargo Ship
Strong projections:
Howard ψ_1 HETEREOGENEOUS QUALITY
Howard ψ_3 TINNINESS (lack of)
SINDSCAL 18 ψ_{2B} BEAT RATE

Figure 13. Analysis of Stimulus 4: Compressed Cavitation.

projection or Howard's ψ_2 which would be interpreted as lack of TINNINESS.

The subjective impression of Compressed Cavitation is one of considerable uniqueness. Its "cranking" quality did not emerge strongly on any dimension, although it did project in the direction of SQUEAKY BEATS.

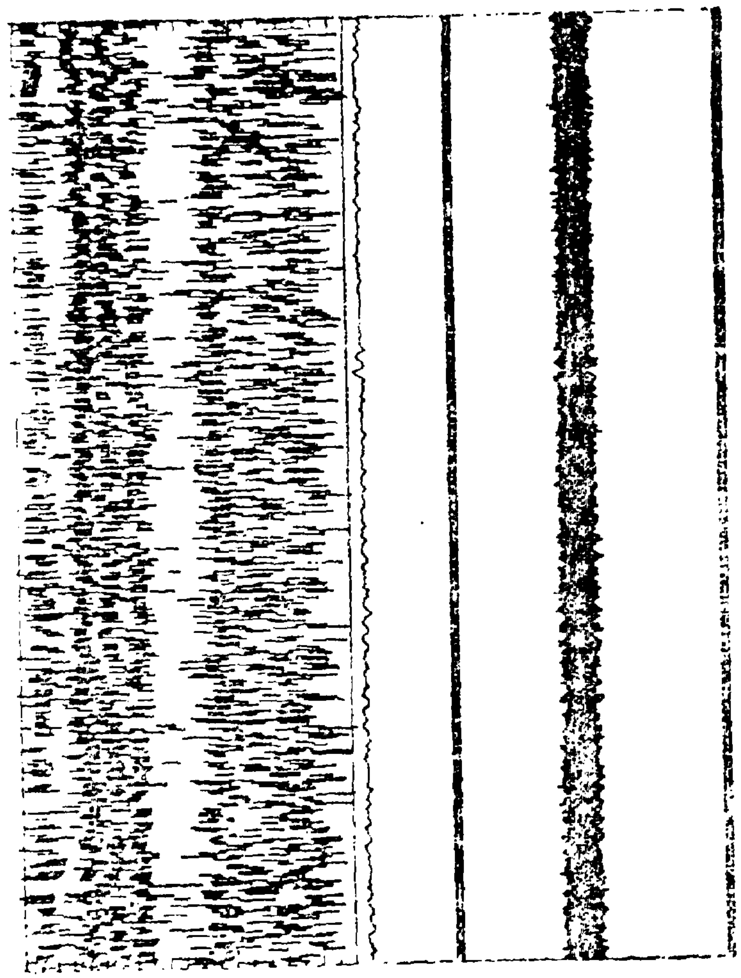
Stimulus 5: Submarine (E)

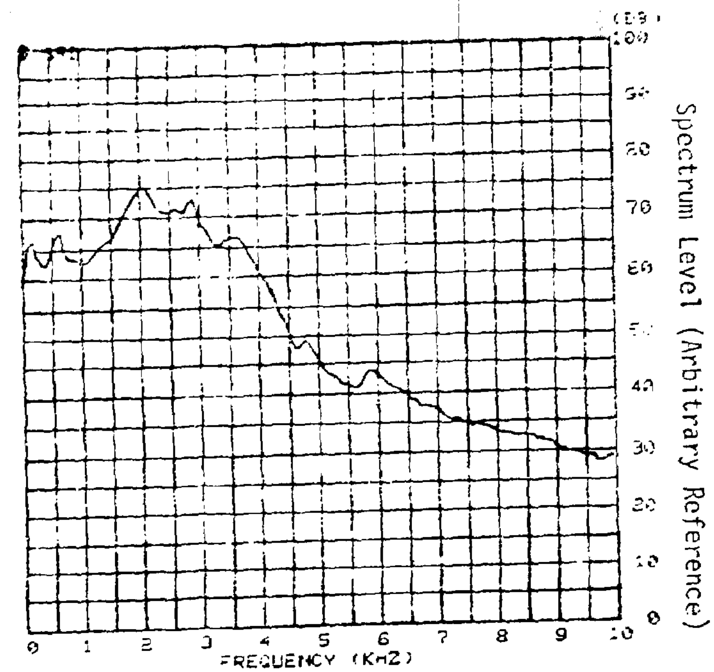
This stimulus (Figure 14) has two pronounced beat rates, rapid and moderate, and is also characterized by broad band hiss. It was one of two stimuli in the set which has a distinctive characteristic that we have dubbed "squeaky." In terms of the Sonar Technician's conceptual stereotypes, this latter characteristic is strongly associated with the submarine class. Ninety-six percent of the technicians classified this target, correctly, in accord with that stereotype.

Submarine (E) projected strongly on ψ_2 in SINDSCAL 14 and ψ_{4E} in SINDSCAL 18 that were clearly the same dimension. We have termed this dimension SQUEAKY BEATS. It also projected on ψ_2 of SINDSCAL 14 and ψ_{1B} of SINDSCAL 18 which in this context implies a lack of TONAL BEATS. This is of interest, since it suggests that squeakiness and tonality are clearly different perceptual characteristics, the latter probably being much more narrow-band in character.

Stimulus 6: Submarine (F)

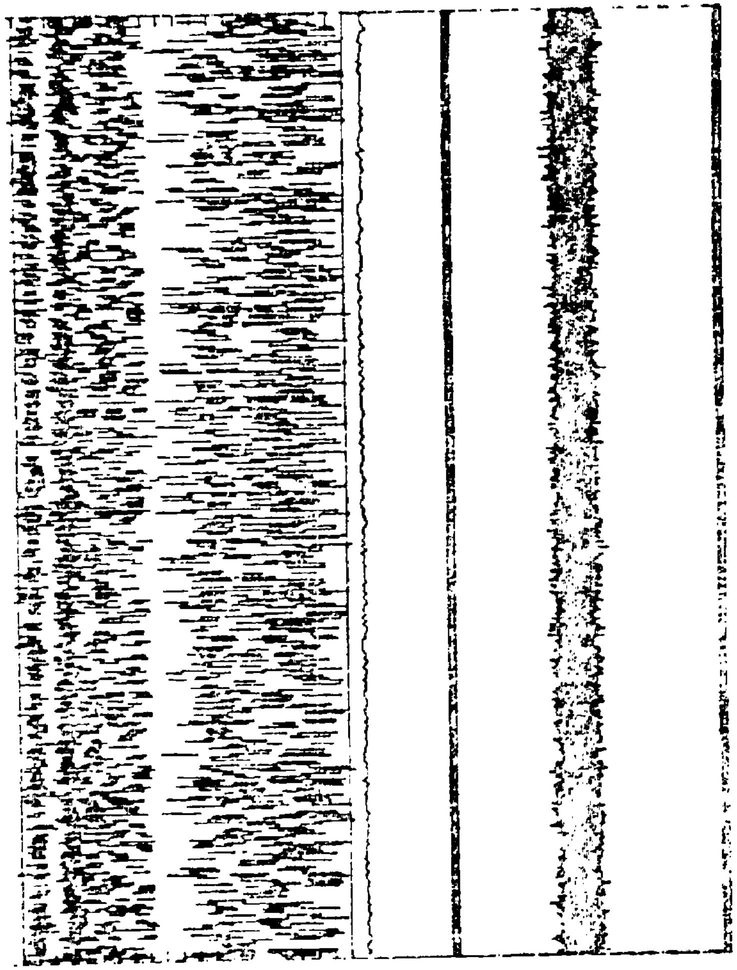
Unlike Submarine E, this signal (Figure 15) is characterized by a very slow beat rate as well as a moderate one, and the beats are quite





Two pronounced beat rates: rapid and moderate
Broadband hiss
"Squeaky"
Closest conceptual stereotype: SUBMARINE
Classification: 25/26 Submarine
Strong projections:
SINDSCAL 14 ψ_3 SQUEAKY BEATS
SINDSCAL 18 ψ_{4B} SQUEAKY BEATS
SINDSCAL 14 ψ_2 BEAT TONALITY (lack of)
SINDSCAL 18 ψ_{1B} BEAT TONALITY (lack of)

Figure 14. Analysis of Stimulus 5: Submarine(E).



(Spectra analysis not available)

Two beat rates, weak and variable
Broadband roar
Closest conceptual stereotype: CARGO SHIP
Classification: 5/26 Submarine
Strong projections:
SINDSCAL 14 γ_1 BEAT CLARITY (lack of)
SINDSCAL 18 γ_{3B} BEAT CLARITY (lack of)

Figure 15. Analysis of Stimulus 6: Submarine(F).

weak and variable. The signal is also characterized by a broadband roar.

Submarine (F) was not viewed as strongly related to the SUBMARINE stereotype; indeed, it was rated slightly more like the CARGO SHIP stereotype than submarine. However, it was not considered by the Sonar Technicians to strongly resemble either stereotype.

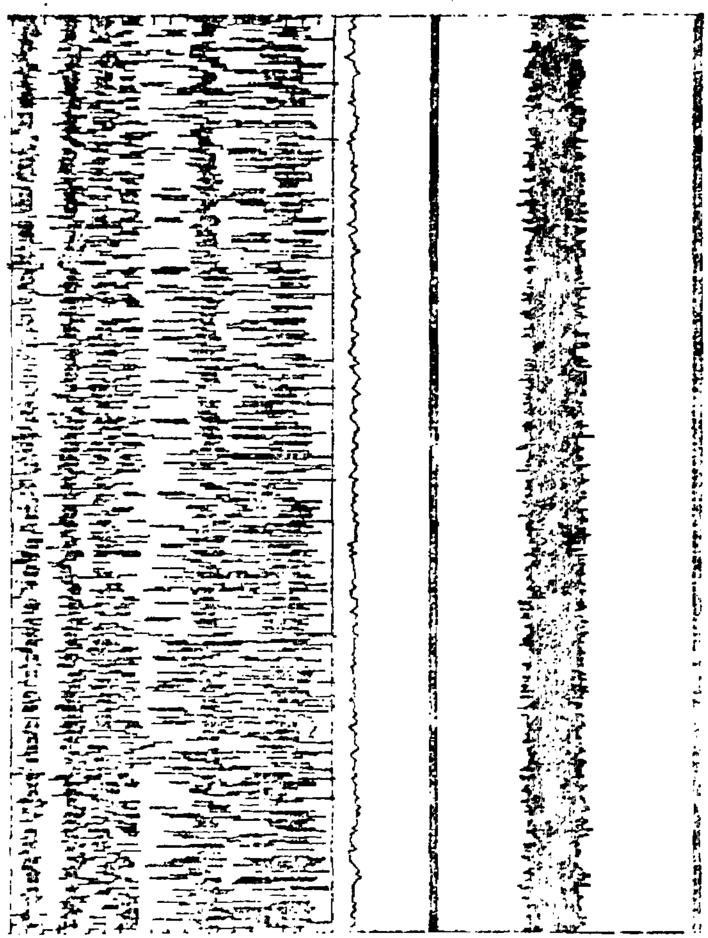
The ambiguity of this stimulus is reflected in the classification scores. Only 19 percent of the Sonar Technicians correctly classified this stimulus, while 54 percent incorrectly classified it as "cargo ship" which it was viewed as resembling most strongly.

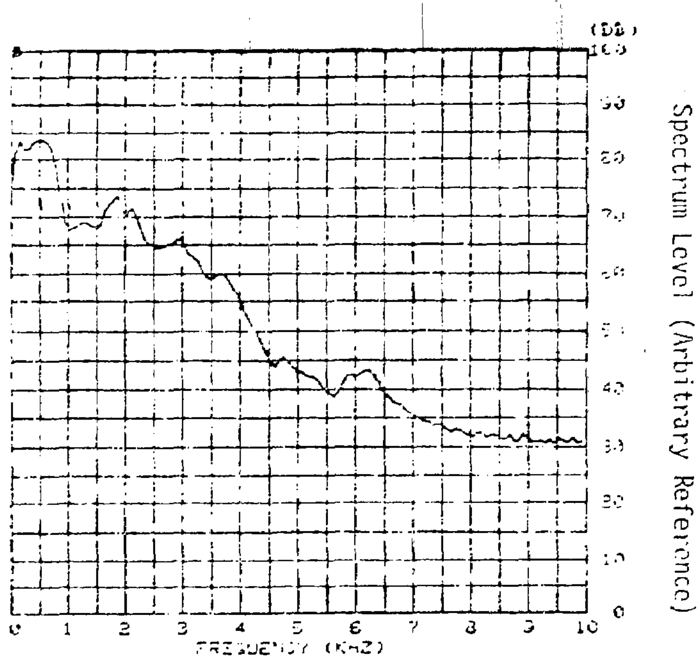
In terms of the SINDSCAL analysis, Submarine (F) showed remarkably few strong projections. It appeared on ψ_1 in SINDSCAL 14 and ψ_{3B} in SINDSCAL 18 which we interpret as a lack of BEAT CLARITY. Submarine (F) also projected on ψ_2 of SINDSCAL 18 in company with Cargo Ships and Compressed Cavitation, a dimension that is characterized by very slow beats. It appears that the stronger of the two beat rates, which was very slow, was responsible for the association with Cargo Ships.

Stimulus 7: Submarine (G)

Submarine (G) was characterized by pronounced rapid beats and a secondary slower beat (Figure 16). It was also described as having a broadband roar resembling the sound of wind and a squeaky or cranking character.

This stimulus was judged by Sonar Technicians to closely resemble the SUBMARINE stereotype and, indeed, 96 percent classified it as "submarine". It was similar to Submarine (E), both in its resemblance





Pronounced rapid beat; moderate second beat
Broadband roar (wind)
"Squeaky" "Cranking"
Closest conceptual stereotype: SUBMARINE
Classification: 25/26 Submarine
Strong projections:
- SINDSCAL 14 ψ_3 SQUEAKY BEATS
- SINDSCAL 18 ψ_{4B} SQUEAKY BEATS
- SINDSCAL 14 ψ_2 TONAL BEATS (lack of)

Figure 16. Analysis of Stimulus 7: Submarine(G).

to the SUBMARINE stereotype and in its projections on the perceptual dimensions. Both Submarines (E) and (G) differed remarkably in this respect from Submarine (F).

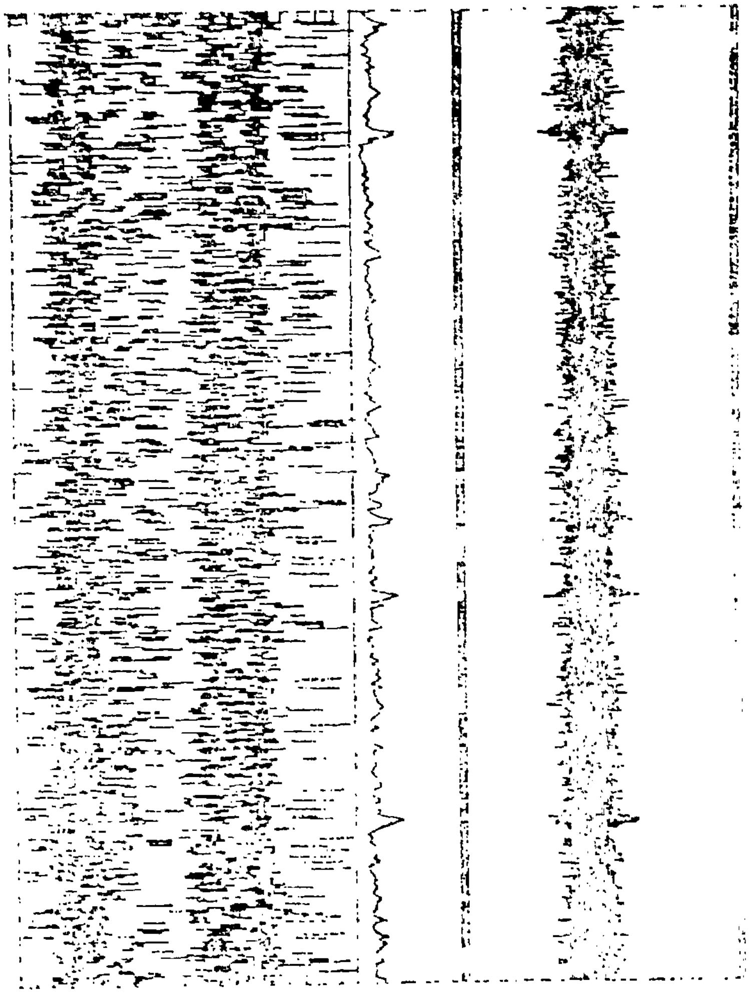
Submarine (G) projected strongly on ψ_3 of SINDSCAL 14 and ψ_{4B} of SINDSCAL 18, a dimension that we labeled SQUEAKY BEATS. It also projected strongly on ψ_2 in SINDSCAL 14 which indicates an absence of TONAL BEATS. While it may be argued that a "squeak" has some tone, the character of the stimuli defining this dimension was clearly different from the more homogeneous and continuous tonal quality of stimuli that projected strongly on TONAL BEATS.

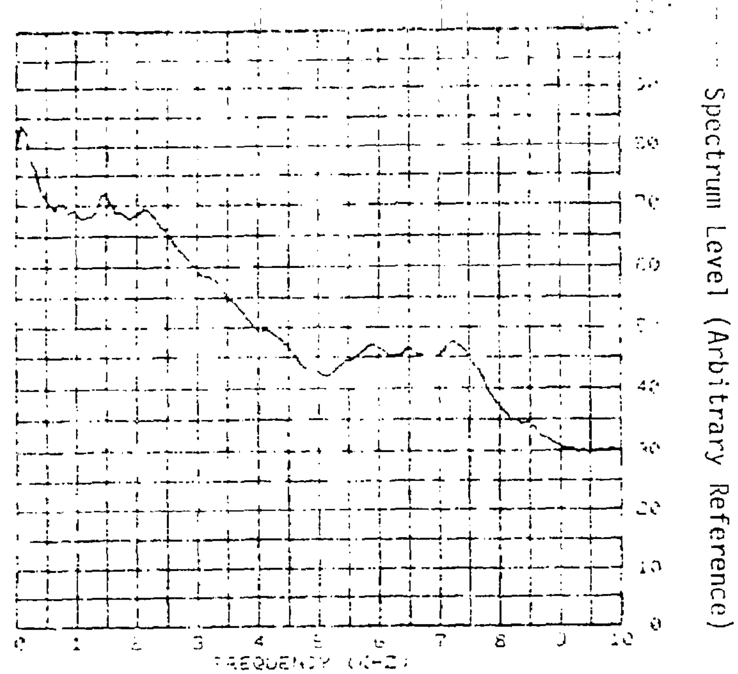
Stimulus 8: Warship (H)

Warship (H) is a very complex signal characterized by two perceptible beat rates, one of which was described as a pronounced "thumping" (Figure 17). The signal also had a somewhat narrowband quality or "electric motor sound." Broadband hiss was also heard.

The Sonar Technicians judged this signal to resemble the WARSHIP stereotype more than any other class, but it was also perceived to have the qualities of CARGO SHIP. Despite this, the classification response was in strong accord with the actual target class, with 81 percent of the Sonar Technicians classifying this stimulus correctly. Probably, the 30-second exposure to the signal during the classification task of Experiment 2 provided an opportunity to discern more "warship" qualities in the signal than was possible during the 6 second exposure on which the conceptual stereotype judgments were based.

Warship (H) projected most strongly on dimension ψ_4 (SINDSCAL 14) which was identified as RAPID BEATS. It also projected strongly





Pronounced moderate beat (thump); rapid weaker beat
Broadband hiss
"Electric motor" sound
Closest conceptual stereotype: WARSHIP
Classification: 21/26 Warship
Strong projections:

- SINDSCAL 14 .4 BEAT RATE
- SINDSCAL 18 .28 BEAT RATE
- SINDSCAL 14 .2 BEAT TONALITY
- SINDSCAL 14 .3 SQUEAKY BEATS (lack of)
- SINDSCAL 18 .48 SQUEAKY BEATS (lack of)

Figure 17. Analysis of Stimulus 8: Warship(H).

on ψ_2 (SINDSCAL 14), which was defined as BEAT TONALITY, and on ψ_3 (SINDSCAL 14) and ψ_{4B} (SINDSCAL 18) which would be interpreted as a lack of SQUEAKY BEATS.

Stimulus 9: Warship (I).

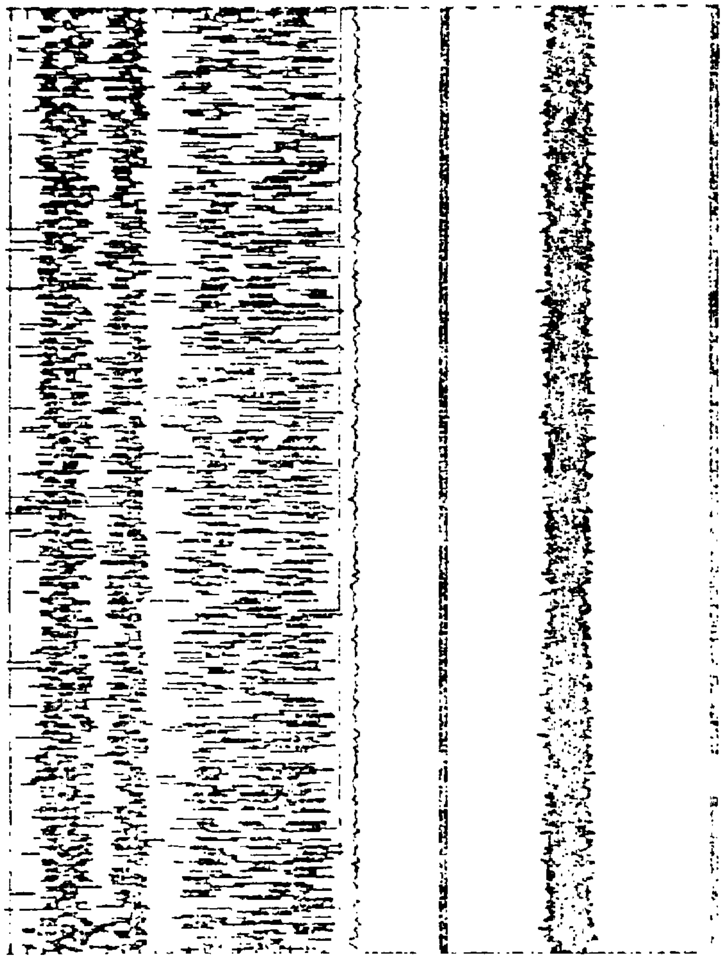
Warship (I) was characterized by an extremely weak, moderate beat rate and a very dominant background hiss (Figure 18). It had no evident narrowband quality. The modulations were quite difficult to perceive.

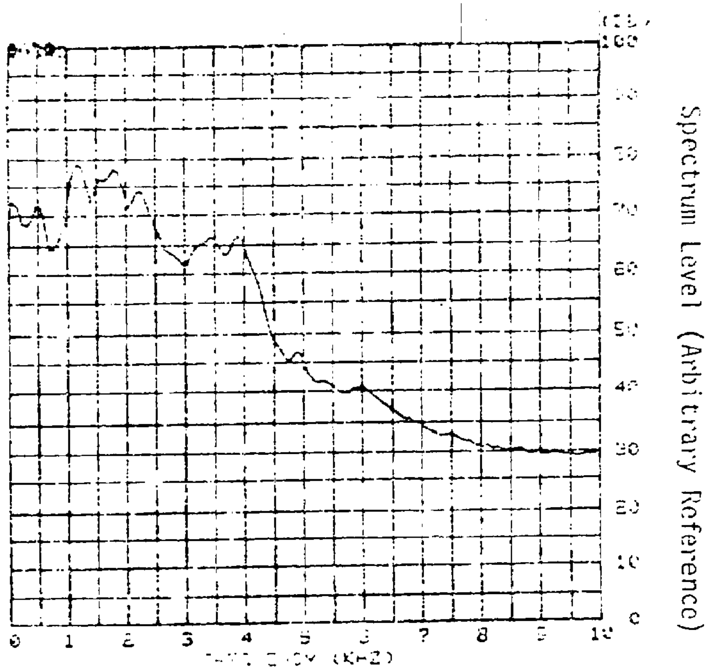
The Sonar Technicians judged Warship (I) to relate most strongly to the LIGHT CRAFT concept, although it also received relatively strong ratings of similarity to the SUBMARINE and WARSHIP stereotypes. Its resemblance to the LIGHT CRAFT stereotype was sufficiently strong that 50 percent of the observers classified this stimulus as a light craft, while only 23 percent correctly identified it as a warship.

Warship (I) has its strongest projections on ψ_{4B} (SINDSCAL 18), lack of SQUEAKY BEATS; on ψ_{1B} (SINDSCAL 18), lack of BEAT TONALITY; and on ψ_1 (SINDSCAL 14) and ψ_{3B} (SINDSCAL 18) which would be defined as lack of BEAT CLARITY. In general, this stimulus can be described more by the absence of definitive characteristics than by their prominence, and this may very well be responsible for the substantial difficulty experienced in correctly classifying it.

Stimulus 10: Warship (J).

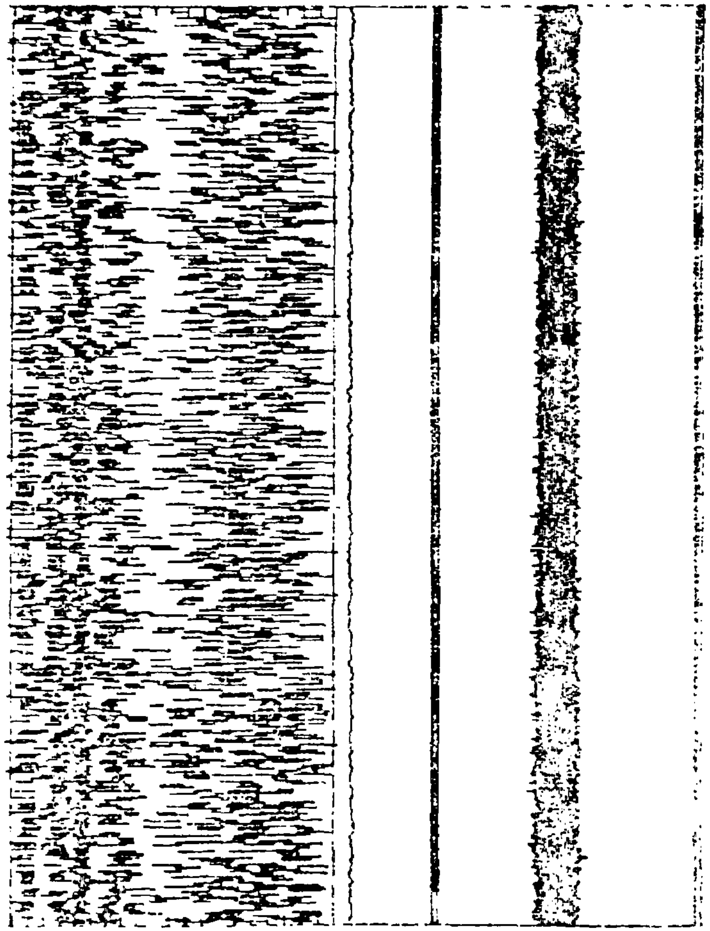
Warship (J) was also characterized by a weak, moderate beat rate and background hiss (Figure 19). In addition, Warship (J) was described as having a "buzzy" character.

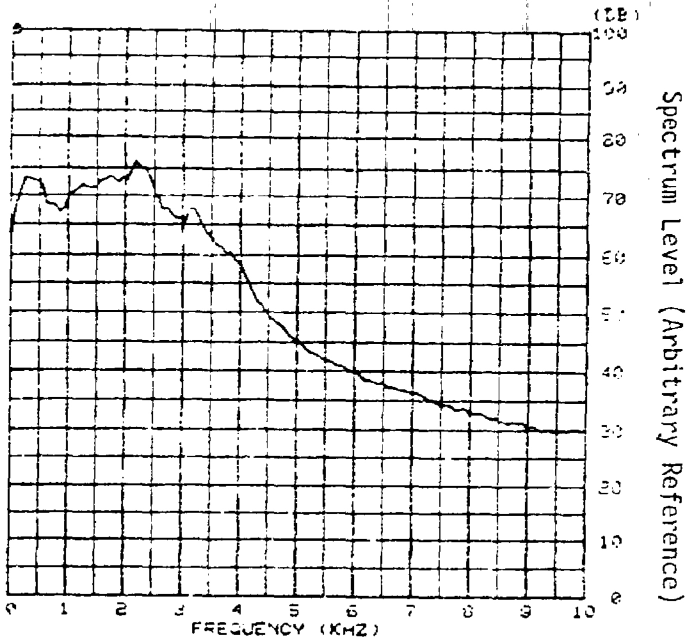




Very weak, moderate rate beat
Broadband hiss - very strong
Closest conceptual stereotype: LIGHT CRAFT
Classification: 6/26 Warship
Strong projections:
SINDSCAL 14 .1 BEAT CLARITY (lack of)
SINDSCAL 18 .2B BEAT CLARITY (lack of)
SINDSCAL 18 .4B SQUEAKY BEATS (lack of)
SINDSCAL 18 .1B BEAT TONALITY (lack of)

Figure 19. Analysis of Stimulus 9: Warship(I).





Weak, moderate rate beats
Broadband hiss
"Buzzy"
Closest conceptual stereotype: WARSHIP
Classification: 11/26 Warship
Strong projections:
SINDSCAL 14 ψ_2 BEAT TONALITY
SINDSCAL 18 ψ_{48} SQUEAKY BEATS (lack of)

Figure 19. Analysis of Stimulus 10: Warship(J).

The Sonar Technicians rated this stimulus as resembling the WARSHIP stereotype more closely than any other, but it was regarded as having some resemblance to all three of the other target classes. Certainly its characteristics were not regarded as being strongly stereotypical of the class to which it belonged. Forty-two percent of the technicians classified the target correctly, while the other classification responses were distributed about equally among the other three target classes.

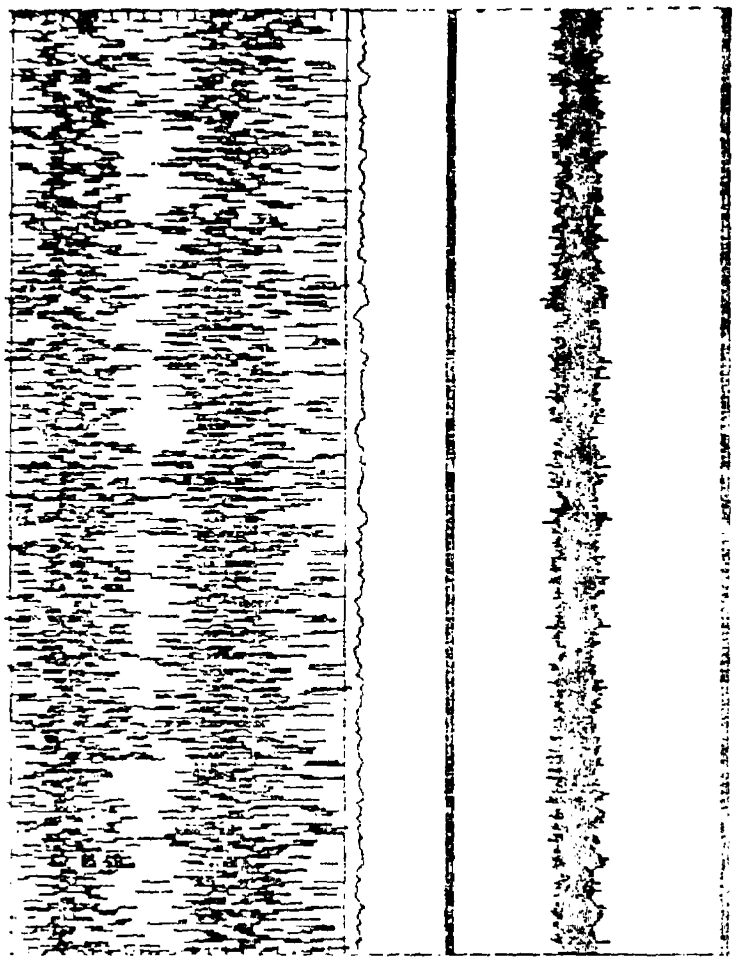
Warship (J) had strong projection on ψ_2 (SINDSCAL 14) which was defined as BEAT TONALITY. The "buzzy" characteristic of this signal may have been responsible for this result. It also projected strongly on ψ_{4B} (SINDSCAL 18), indicating absence of SQUEAKY BEATS.

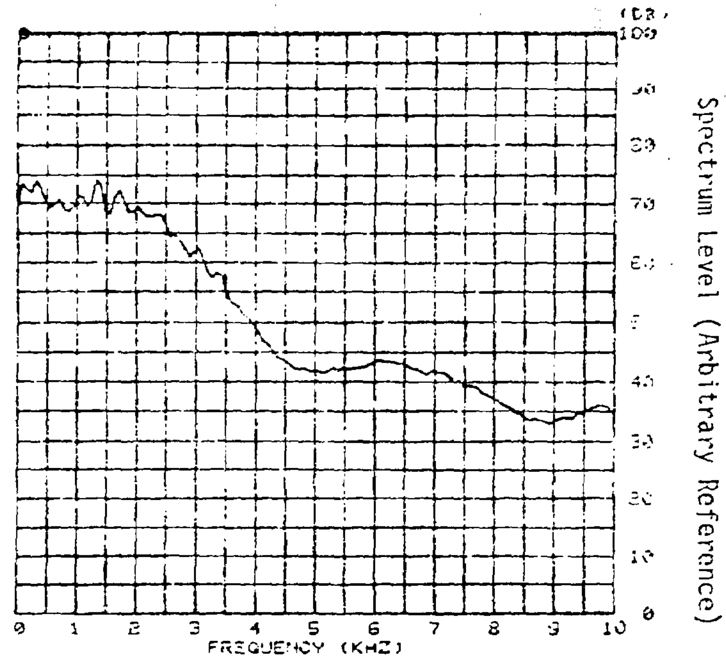
Stimulus 11: Cargo Ship (K).

Cargo Ship (K) had two pronounced beat rates, one of which was quite slow and the other moderate (Figure 20). Other than this, the most salient characteristic of this stimulus was its clear tonal character which was modulated in accord with the slower of the two beat rates.

The Sonar Technicians strongly associated this stimulus with the CARGO SHIP stereotype and classified Cargo Ship (K) with a high degree of success, 85 percent of the classification judgments being correct.

Cargo Ship (K) was a dominant stimulus in the SINDSCAL 14 and SINDSCAL 18 analyses with strong projections on ψ_2 (SINDSCAL 14) and ψ_{1B} (SINDSCAL 18). Because of its strong pulsed-tone, we tentatively identified these dimensions as BEAT TONALITY. It also projected strongly on ψ_3 (SINDSCAL 14) which is interpreted as a





Pronounced moderate rate and slow beats
Broadband hiss (weak)
Strong tonal quality to beats
Closest conceptual stereotype: CARGO SHIP
Classification: 22/26 Cargo Ship
Strong projections:

SINDSCAL 14 ϕ_2	BEAT TONALITY
SINDSCAL 18 ϕ_{1B}	BEAT TONALITY
SINDSCAL 14 ϕ_3	SQUEAKY BEATS (lack of)
SINDSCAL 14 ϕ_4	BEAT RATE (slow)
SINDSCAL 18 ϕ_{2B}	BEAT RATE (slow)

Figure 20. Analysis of Stimulus 11: Cargo Ship (K).

lack of SQUEAKY BEATS. It further projected on ψ_4 (SINDSCAL 14) and ψ_{2B} (SINDSCAL 18) indicating that it is characterized by a slow BEAT RATE.

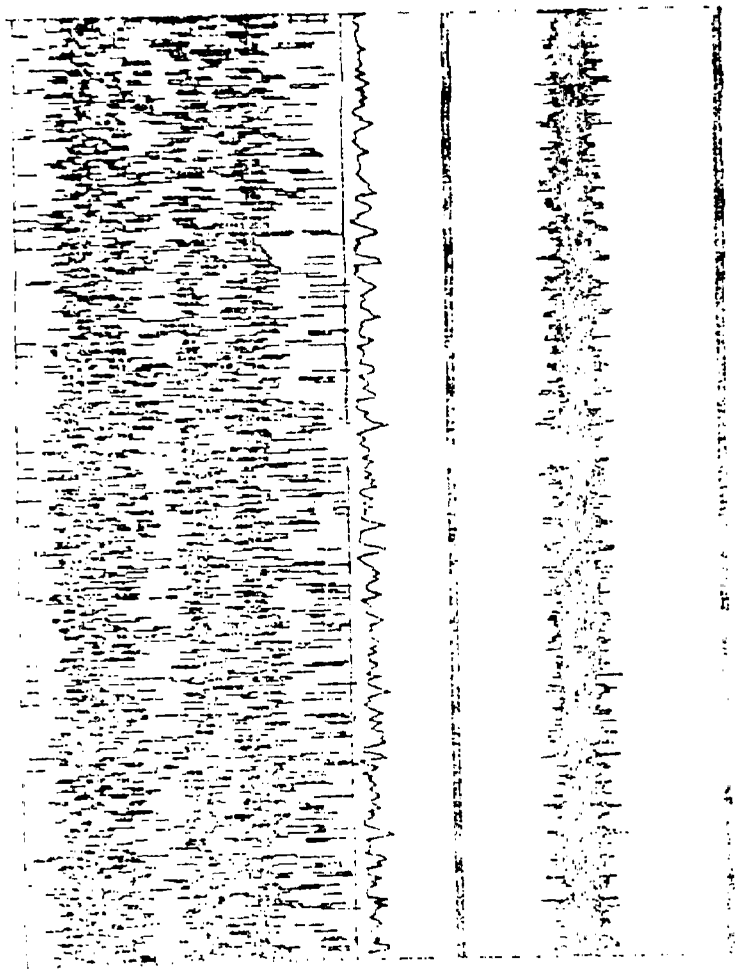
Very likely, both the slow beat rate and the tonal character of Cargo Ship (K) was responsible for its strong association with the CARGO SHIP stereotype. The following example which was also a Cargo Ship stands in marked contrast to this example.

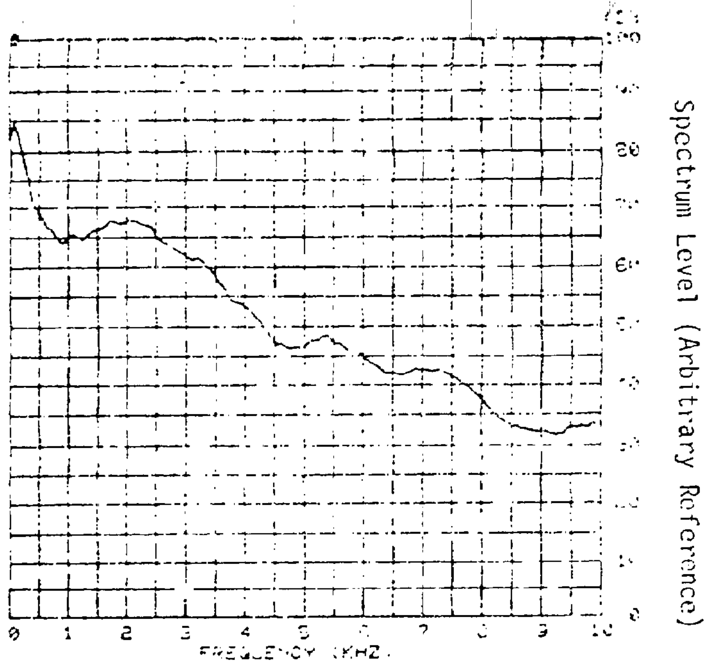
Stimulus 12: Cargo Ship (L).

Cargo Ship (L) is characterized by two beat rates, one of which is quite rapid and pronounced, while the other is slower and much weaker (Figure 21). The more rapid beat rate has a "static," atonal character. The stimulus is also characterized by background hiss.

The Sonar Technicians most strongly associated Cargo Ship (L) with the LIGHT CRAFT stereotype. Its judged resemblance to its true class was quite weak, and it was more closely associated with WARSHIP than with CARGO SHIP. As a result, only 15 percent of the listeners correctly classified this target, the great preponderance (73 percent) classifying it in accord with its dominant stereotype (LIGHT CRAFT).

A clue to the source of classification error is provided by the projections of Stimulus 12 on the various perceptual dimensions. Cargo Ship (L) projected strongly on ψ_4 (SINDSCAL 14) and ψ_{2B} (SINDSCAL 18), rapid BEAT RATE, in direct opposition to the slow beat rate often associated with Cargo Ships. It will be recalled that Flutter (E), also projected strongly on this dimension and that Flutter is often associated conceptually with light craft. Cargo Ship (L) also





Pronounced rapid beat and weak slower beat
Broadband hiss
"Static" character to beats
Closest conceptual stereotype: LIGHT CRAFT
Classification: 4/26 Cargo Ship
Strong projections:
SINDSCAL 14 .4 BEAT RATE
SINDSCAL 18 .2B BEAT RATE
SINDSCAL 14 .1 BEAT CLARITY
SINDSCAL 18 .3B BEAT CLARITY

Figure nalysis of Stimulus 12: Cargo Ship (L).

projected strongly on ψ_1 (SINDSCAL 14) and ψ_{3B} (SINDSCAL 18) which we regarded as BEAT CLARITY.

Stimulus 13: Light Craft (M).

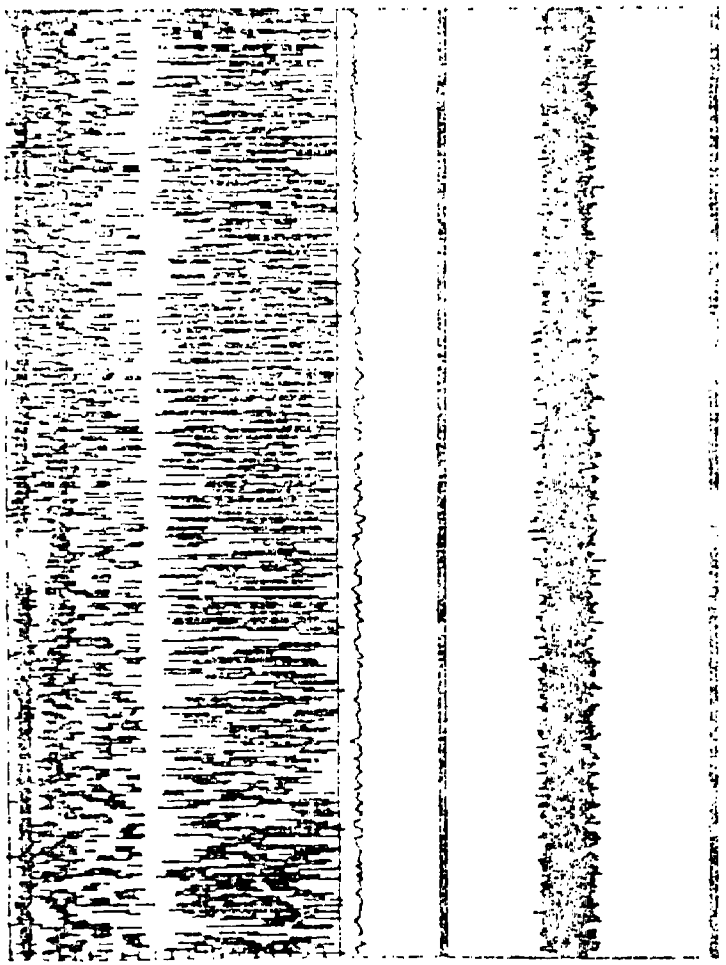
Light Craft (M) was characterized by a very rapid, very weak beat rate (Figure 22). In addition, it was described as having a dominant background roar. It had no perceptible narrowband characteristics.

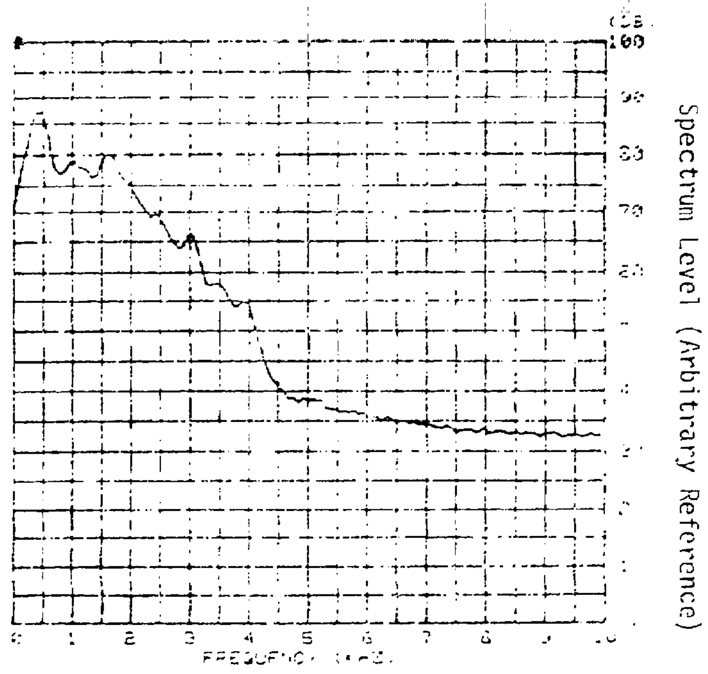
The Sonar Technicians associated this stimulus most strongly with the WARSHIP stereotype but almost equally so with SUBMARINE. In contrast, its association with its true target class, was quite weak. As a result, only 38 percent of the technicians classified this target correctly whereas 42 percent incorrectly classified it as a warship.

Light Craft (M) is characterized by very few strong projections on any of the perceptual dimensions, a fact which may be responsible for the difficulty Sonar Technicians encountered in classifying it. Its strongest projections were on ψ_1 (SINDSCAL 14) and ψ_{3B} (SINDSCAL 18) which is translated as lack of BEAT CLARITY. It is associated with other stimuli, such as Submarine (F) and Warship (I) that had very weak, barely perceptible beats, as well as background roar. In general, its lack of definitive characteristics, particularly a clear beat rate, apparently led not only to difficulty in the classification task but to an absence of clear perceptual dimensionality.

Stimulus 14: Light Craft (N).

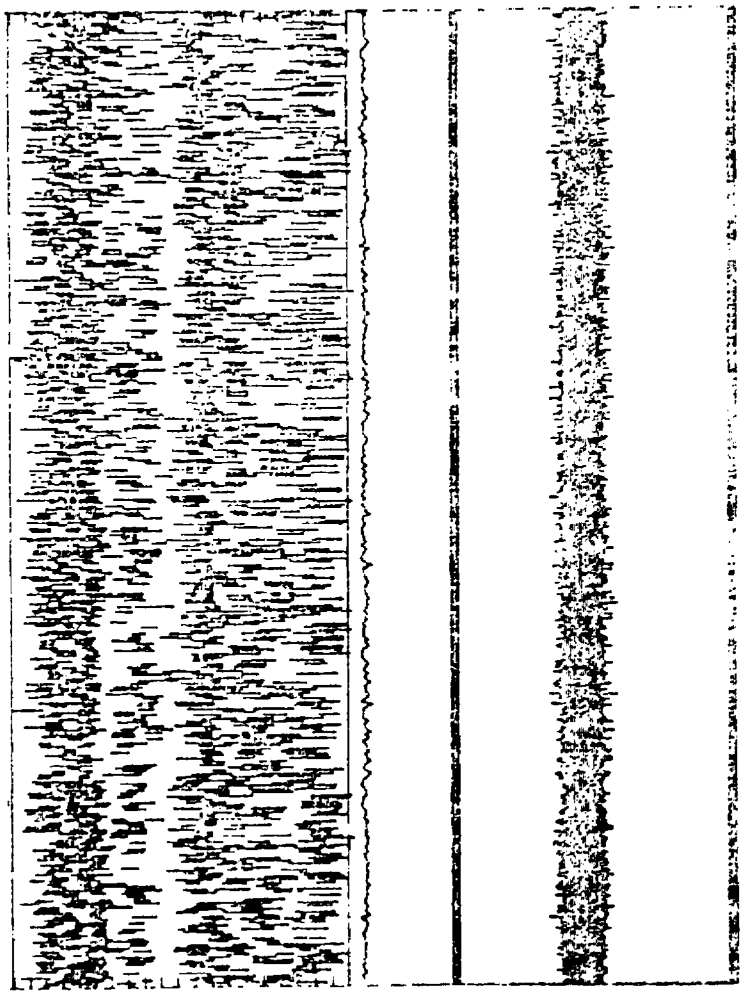
Light Craft (N) was also characterized by a weak, moderate beat rate (Figure 23) although not as weak as Light Craft (M). In addition, its background was characterized by a low pitched narrow band hum.

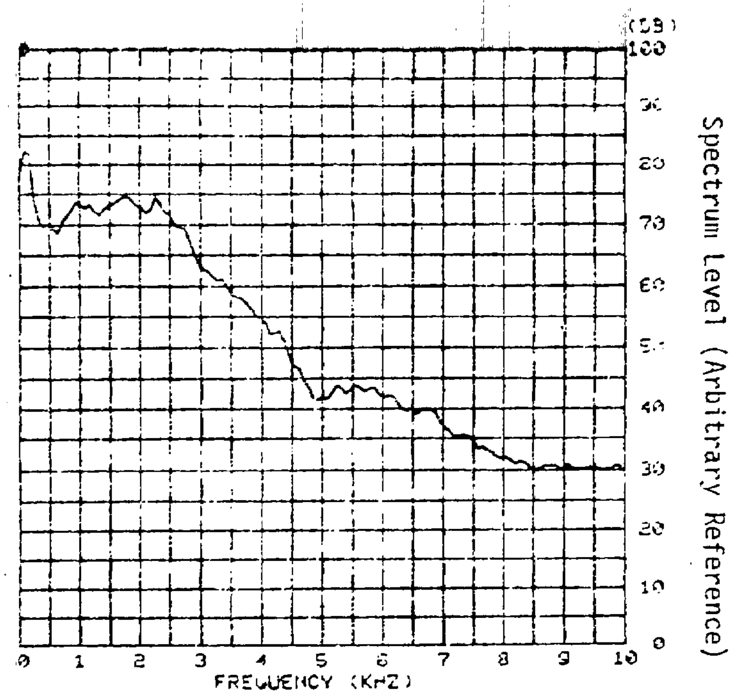




Very weak rapid beat
Strong broadband "roar"
Closest conceptual stereotype: WARSHIP
Classification: 10/26 Light Craft
Strong projections:
SINDSCAL 14 .1 BEAT CLARITY (lack of)
SINDSCAL 18 .38 BEAT CLARITY (lack of)

Figure 22. Analysis of Stimulus 13: Light Craft(M).





Weak, moderate beat rate
Weak broadband hiss
Low pitched "humm"
Closest conceptual stereotype: CARGO SHIP
Classification 3/26 Light Craft
Strong projections:
SINDSCAL 14 $_2$ BEAT TONALITY

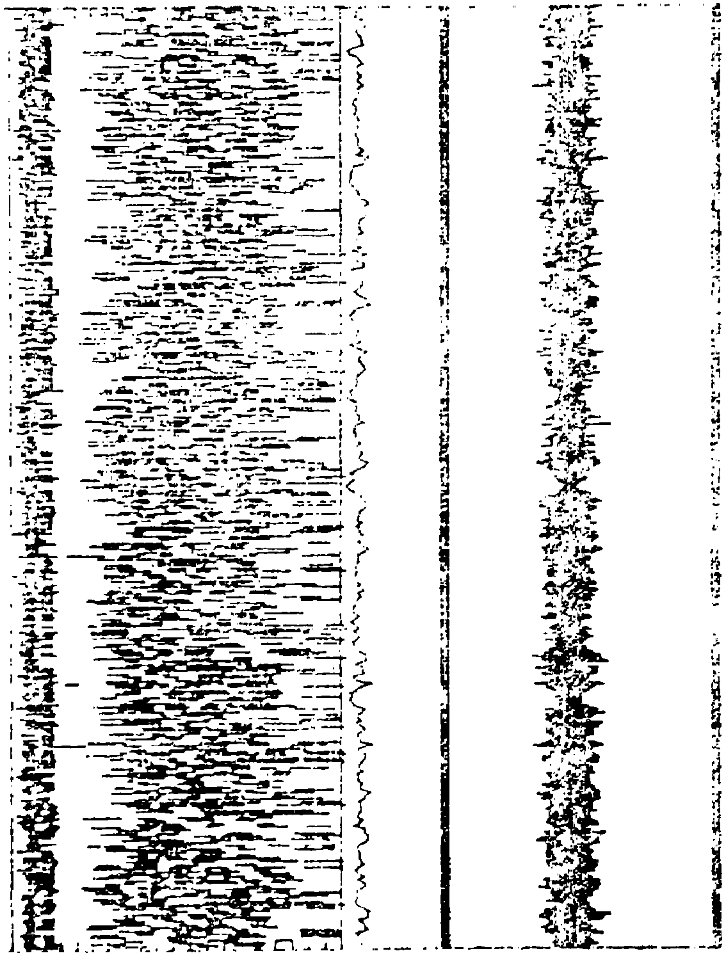
Figure 23. Analysis of Stimulus 14: Light Craft(M).

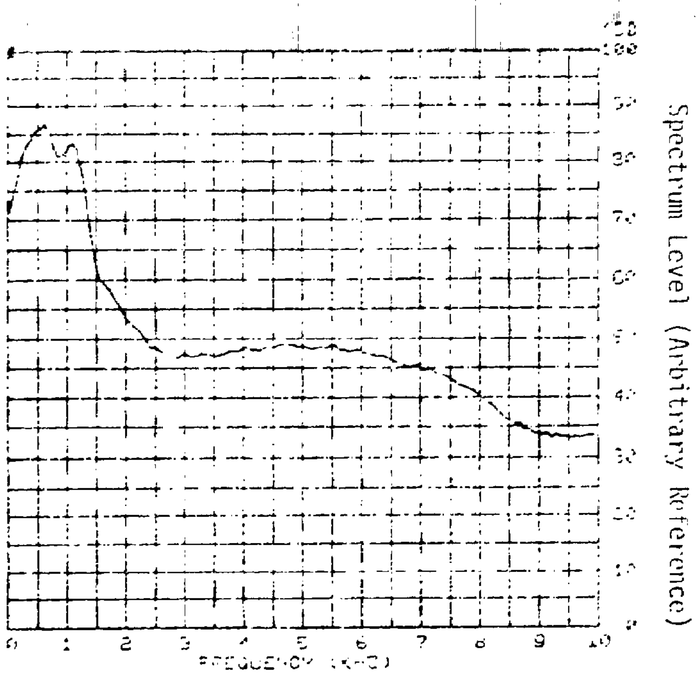
The Sonar Technicians associated this stimulus with two target class stereotypes, neither of which was correct: CARGO SHIP and WARSHIP. The weakest association with all four classes was with the correct one, LIGHT CRAFT. Not surprisingly, only 12 percent of the technicians correctly classified this target, whereas 27 percent classified it as a Cargo Ship and 46 percent as a Warship.

The strongest projection of Light Craft (N) was on ψ_2 (SINDSCAL 14) which we identified as BEAT TONALITY. It shares company in this regard with Cargo Ship (K) and Warship (J) both of which had somewhat clearer tonal pulsing. Other than this, Stimulus 14 is nondescript with respect to the perceptual dimensions identified during this study. It is evident that it possesses few of the characteristics associated with the LIGHT CRAFT stereotype and must be regarded as another example of why classification by nature of sound is such a complex task.

Remaining Stimuli

The remaining five stimuli that were employed in Experiment 1 and Howard's original study, but not in Experiment 2, were also physically and subjectively analyzed. The results for these stimuli (Biologics [Figure 24], Torpedo [Figure 25], Diesel Engine [Figure 26], Rain Squall [Figure 27], and Steam Noise [Figure 28]) are presented on the following pages. The perceptual dimensions on which they had strong projections are generally quite meaningful from the viewpoint of target classification, though there is no way of knowing, of course, which additional dimensions might have entered into their descriptions had they been included in Experiment 2.





Pronounced, irregular, moderate rate beat
Broadband hiss and roar
"Chirpy"
Classification: 24/26 Biologics
Strong projections:

Howard ϕ_1 BEAT RATE (lack of)

HFP 8 ϕ_1 BEAT RATE (lack of rapid)

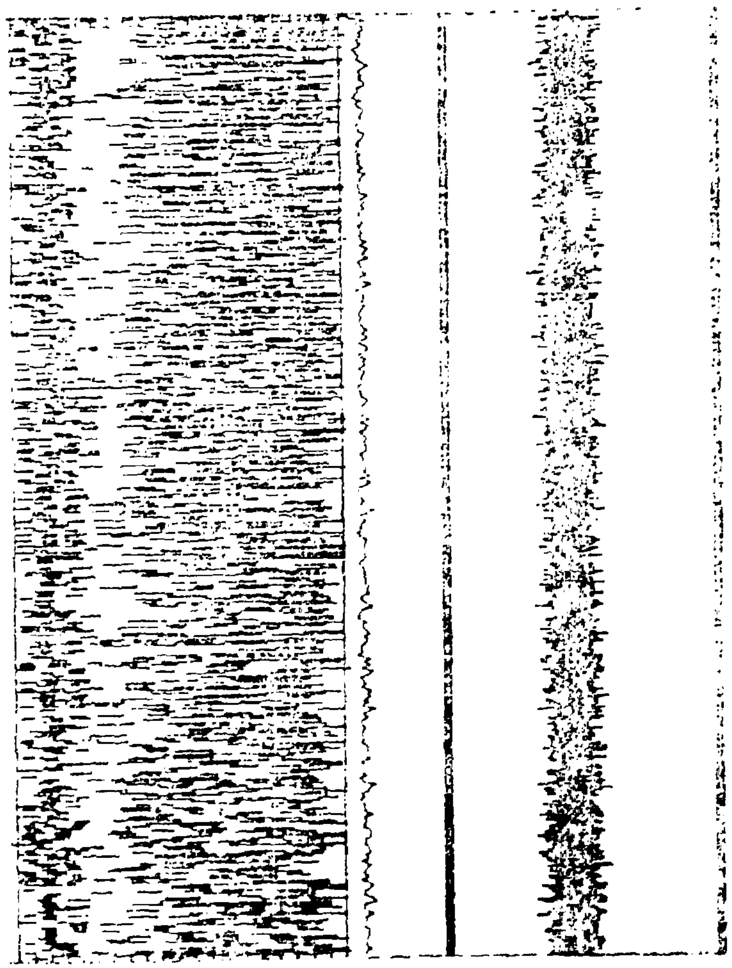
Howard ϕ_2 LOW FREQUENCY PERIODICITY

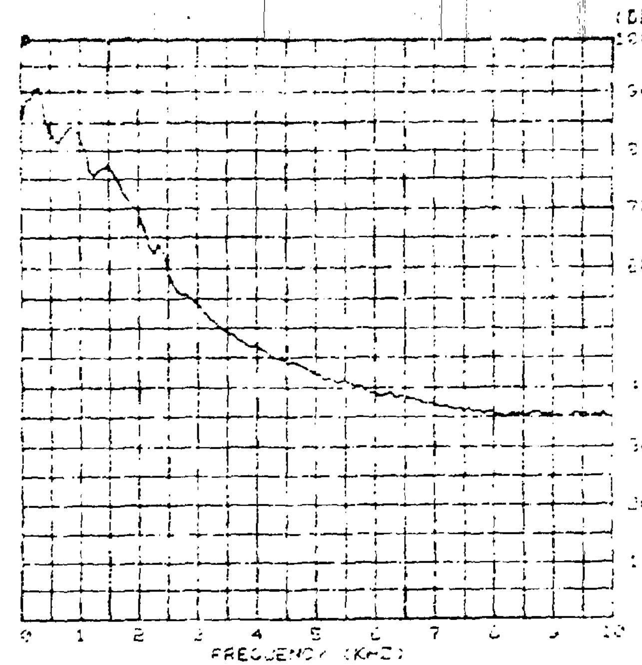
HFP 8 ϕ_3 BEAT CLARITY

Howard ϕ_3 TINNINESS

HFP 8 ϕ_2 TONALITY

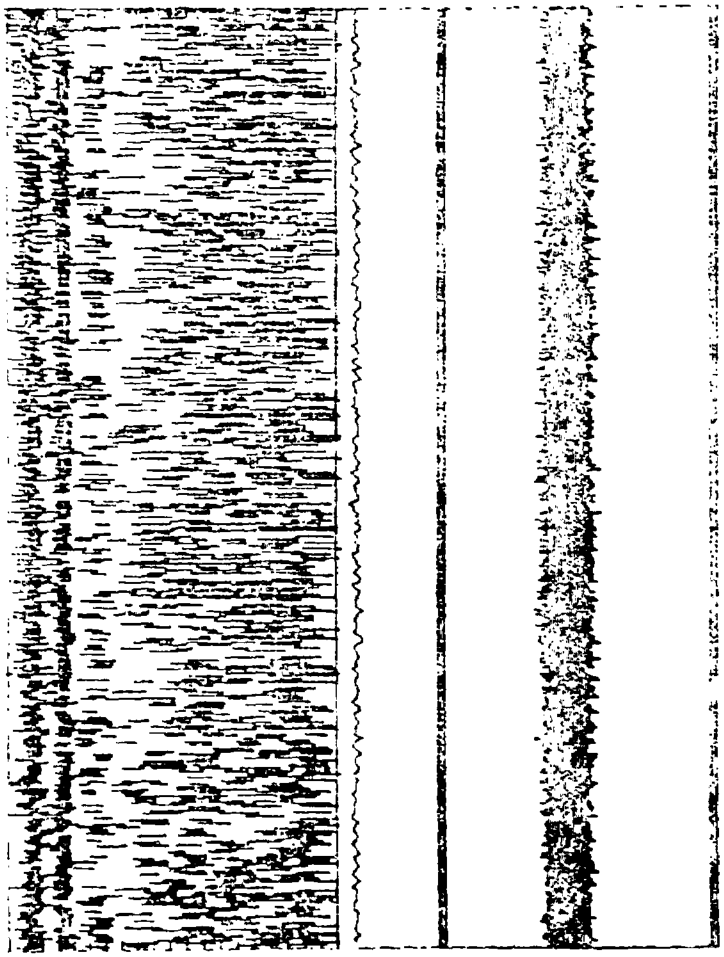
Figure 24. Analysis of Stimulus 13: Biologics(BI).

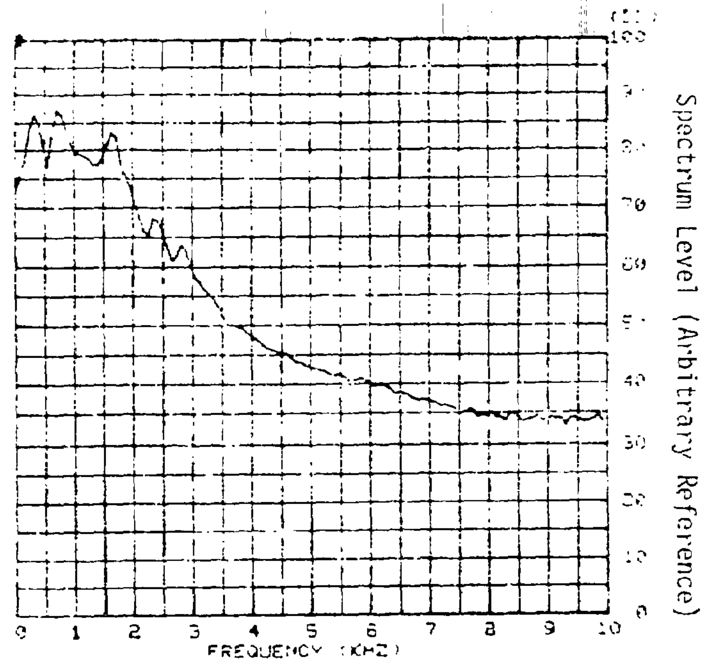




Weak, rapid beats
Broadband hiss
"Electric motor" sound
Classification: 24/26 Torpedo
Strong projections:
HFR 8 v_1 BEAT RATE
HFR 8 v_2 TONALITY
HFR 8 v_3 BEAT CLARITY

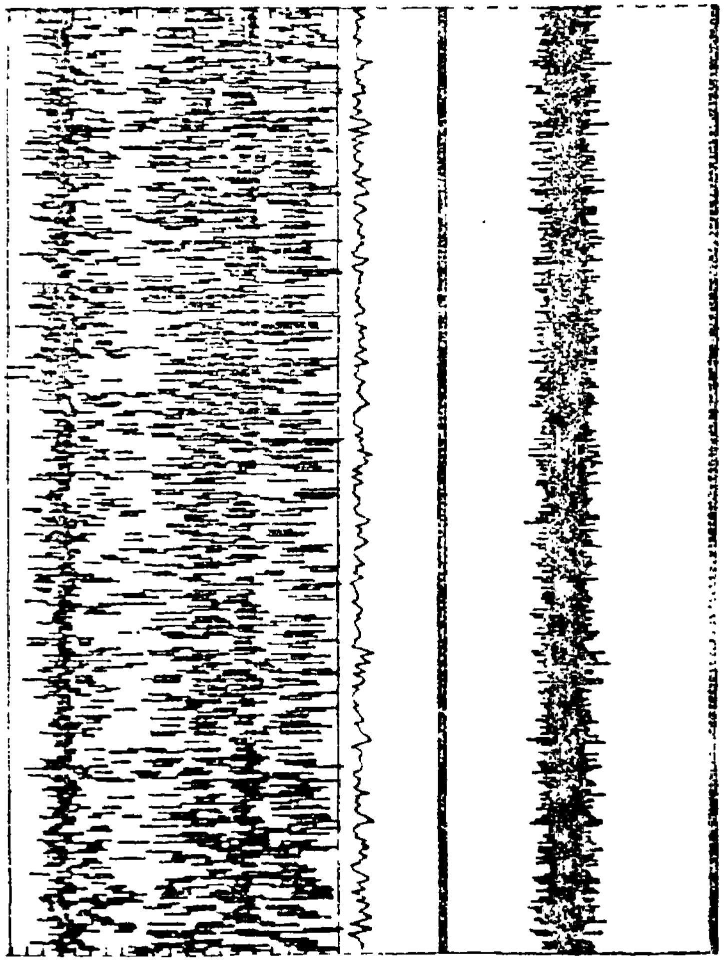
Figure 25. Analysis of Stimulus 19: Torpedo(TO).

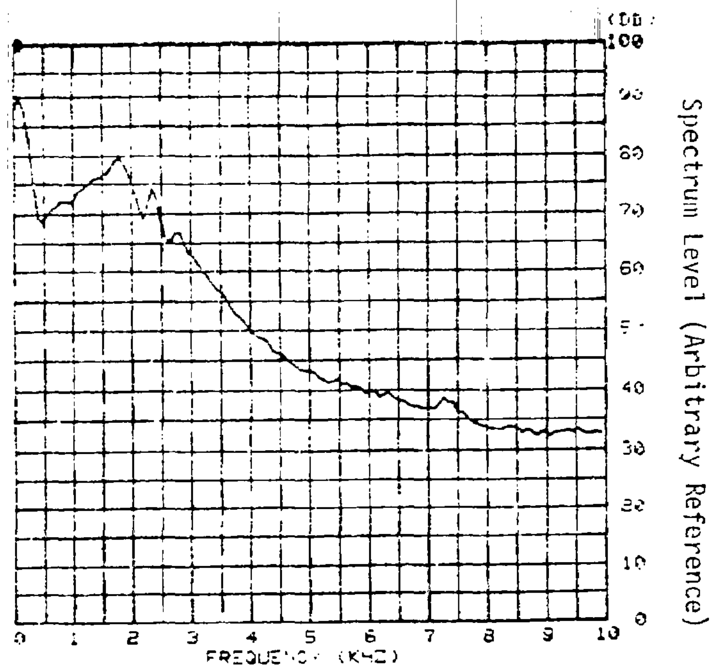




No discernible beat
Weak broadband roar
Moderate and high pitched narrowband quality
"Machinery" sound
Classification: 19/26 Diesel Engine
Strong projections:
Howard ϕ_2 LOW FREQUENCY PERIODICITY (lack of)
HFR 8 ϕ_3 BEAT CLARITY (lack of)
Howard ϕ_3 TINNINESS

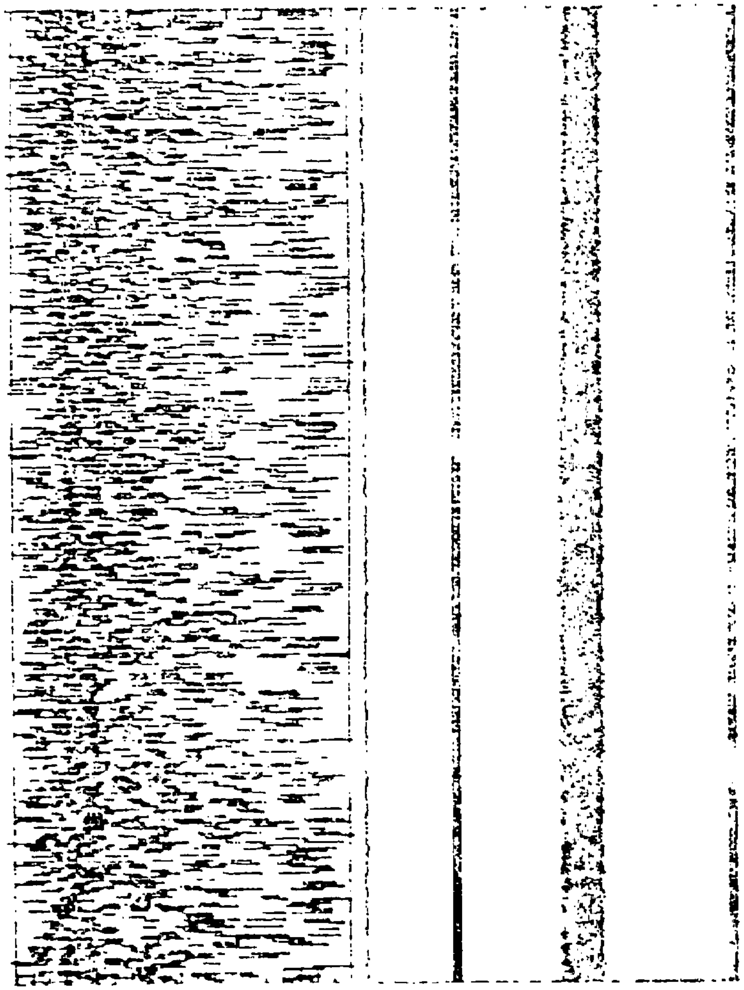
Figure 26. Analysis of Stimulus 17: Diesel Engine (DE).

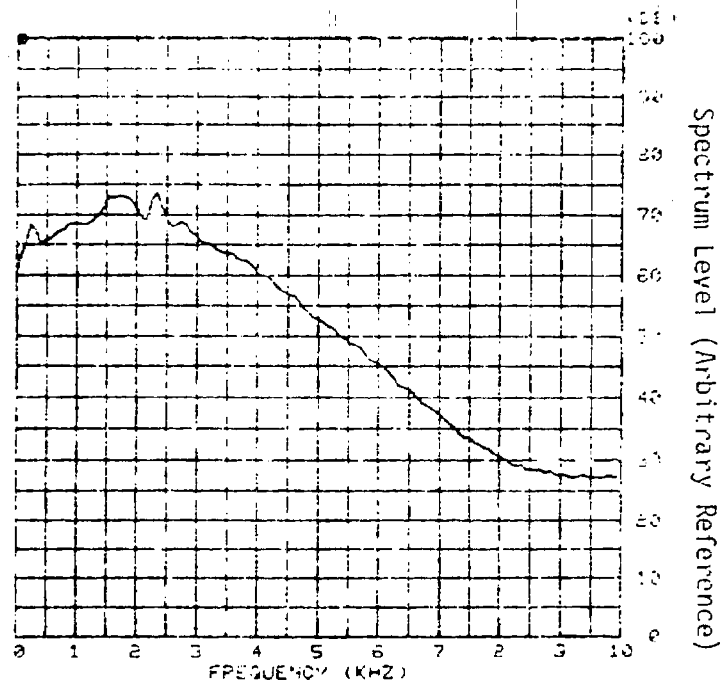




No discernible beat
Broadband hiss and roar
"Hollow" sound
Classification: 14/26 Rain Squall
Strong projections:
Howard .1 HETEROGENEOUS QUALITY

Figure 27. Analysis of Stimulus 18: Rain Squall (RS).





No discernible beats
Strong boradband hiss
Classification: 10/26 Steam Noise
Strong projections:
Howard $._2$ LOW FREQUENCY PERIODICITY (lack of)
HFR 8 $._2$ TONALITY (lack of)

Figure 23. Analysis of Stimulus 19: Steam Noise (SN).

Conclusions

It is evident from the preceding graphs that the sound spectra of the 19 stimuli were different--often quite different--from one another. These differences are tantalizing evidence that the physical analyses chosen do discriminate among the stimuli and promise to illuminate the perceptual process. However, it is not evident from inspection alone how these physical descriptions of the stimuli relate to the psychological descriptions resulting from the SINDSCAL analyses. To determine that relationship, the results of the physical analyses should be quantified and related numerically to the SINDSCAL data by multivariate analysis. Also, additional spectral analysis should be performed to provide greater resolution in the very low frequency regions of the "beat" phenomena subjectively noted in many of the stimuli and subsequently judged to be represented by SINDSCAL dimensions. These studies appear to comprise a logical and promising next step.

SUMMARY AND CONCLUSIONS

On the basis of results obtained from Experiments 1 and 2, it is concluded that:

1. Where common sets of sonar signals are used as stimuli, the group perceptual space underlying the similarity judgments of naive observers and experienced Sonar Technicians is highly similar.
2. Experienced Sonar Technicians attach different salience or importance to particular dimensions than do sonar-naive observers, whether or not the latter are musically trained.
3. The number and nature of perceptual dimensions underlying Sonar Technicians' similarity judgments of sonar signals is a function of the stimulus set; a larger number of dimensions emerged when a larger, more representative sample of signals was used than when a more limited set was used.
4. The similarity judgments of particular pairs of stimuli by individual observers are only moderately reliable (although group average judgments are very reliable). This may be responsible for the fact that only about 60 percent of the variance in the judgments is accounted for by solutions of appropriate dimensionality.
5. Most sonar signals are perceptually quite complex, typically showing strong projections on two or three of the dimensions identified in this and Howard's (1976) earlier study.

6. Each of the dimensions thus far identified (BEAT RATE, BEAT CLARITY, TONALITY (VS. HISS), BEAT TONALITY, SQUEAKY BEATS and, possibly, DUAL BEATS) appears to play an important role in the classification response of Sonar Technicians. The absence of strong projections on any of these dimensions is often associated with classification error. Conversely, very strong projections on only a single dimension is sometimes associated with a high degree of classification success.

7. Several of the dimensions involve perceptions of very low frequency (1 to 20 Hz) periodicity (or aperiodicity) that is likely to require spectral analysis of especially fine resolution to supplement the analyses already performed. Consequently, the question of the physical correlates of the perceptual dimensions identified in this study remains unanswered and should be the subject of further analysis.

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